Introduction

Origin of weeds

Weeds are no strangers to man. They have been there ever since farmer started to cultivate crops about 10,000 BC and undoubtedly recognized as a problem from the beginning. Any plant in the field other than his crop became weed. Again the characters of certain weed species are very similar to that of wild plants in the region. Some of the crops for example including the wheat of today are the derivatives of wild grass. Man has further improved them to suit his own taste and fancy. Even today they are crossed with wild varieties to transfer the desirable characters such as drought and disease resistance. So the weeds are to begin with essential components of native and naturalized flora but in course of time these plants are well placed in new environment by the conscious and unconscious efforts of man. Hence, it is considered that many weeds principally originated from two important and major arbitrarily defined groups.

1. By man’s conscious effort
2. By invasion of plants into man created habits

In the world there are 30,000 weed species, out of these 18,000 sps cause damage to the crops. **Jethro Tull** first coined the term weed in 1931 in the book “**Horse Hoeing Husbandry**”

Definition

Weeds are the plants, which grow where they are not wanted (Jethro Tull, 1731).**Weeds can also be referred to as plants out of place**.

Weeds are unwanted or undesirable plants compete with crops for water, soil nutrients, light and space (ie CO2) and thus reduce crop yields.

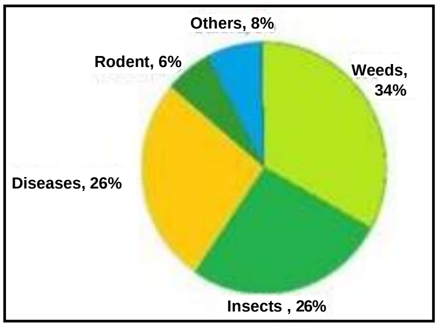
Weeds are competitive and adaptable to all the adverse environments. It has been estimated that in general weeds cause **5%** loss to Agricultural production in most developed countries. **10%** loss in less developed countries and **25%** loss in least developed countries.

The problems of weeds and methods of controlling them have been with farmer since the early days of agriculture. The relatively labour-intensive and less effective methods of the pre-agricultural revolution era were replaced by the concept of crop-rotation and prophylactic measures. The improvement in the implements of mechanization and the introduction of tractor further increased farmer's ability to reduce crop-weed competition. The discovery of the synthetic and relative herbicides, however, empowered the farmer, horticulturist and forester to control broad leaf weeds in broad leaf crops, narrow leaf weeds in narrow leaf crops or broad leaf weeds in narrow leaf crops as well as narrow leaf weeds in broad leaf crops. Long before the beginning of synthetic herbicides, chemicals, mostly of inorganic in nature were reported to be used as weed management practice.

The first herbicide used for selective weed control was copper sulphate, which was tested to control charlock (*Brassica kaber*) in wheat in France. With the beginning of twentieth century, sodium arsenite became very popular in the United States and during the first four decades, it had been widely and extensively used for the control of annual weeds, perennial weeds and submerged aquatic weeds. There are some more reports available on the use of different chemicals like xylene, sodium chlorate, sodium borate, salt of dinitrophenol etc. In the 1930s, dinitro ortho cresol (DNOC) was introduced in agriculture as the first organic herbicide, albeit it did not fetch much success. The real breakthrough came after the invention of 2,4-

dichlorophenoxyacetic acid (2,4-D), the first widely used synthetic herbicide. The property of 2,4-D to act as hormone was discovered independently by four groups in the United States and Great Britain: William G. Templeman and coworkers (1941); Philip Nutman, Gerard Thornton, and Juda Quastel (1942); Franklin Jones (1942); and Ezra Kraus, John W. Mitchell, and Charles L. Hamner (1943) (Troyer 2001). Sherwin-Williams Paint Company was the first to commercialise it in the late 1940s. In the United States, in 1950s and 1960s, 2,4-D replaced millions of agricultural workers formerly employed in weeding. In other words, 2,4-D revolutionized chemical weed control. This was the beginning of designing herbicide molecules specifically tailored to inhibit specific enzyme reaction. Atrazine followed 2,4-D in 1958, and Monsanto's glyphosate in 1974. Thereafter, around 2000 different herbicide molecules of 15 different modes of action have been introduced in the global market.

The earliest attempt to control weeds in India with herbicides was made in 1937 in Punjab for controlling *Carthamus oxyacantha* by using sodium arsenite. 2,4-D was first tested in India in 1946. Since then a number of herbicides have been imported and tried for their effectiveness in controlling many weed species. In 1952, ICAR initiated schemes for testing the field performance of herbicides in rice, wheat and sugarcane in different states of India. The era of herbicide-use started effectively with the import of 2,4-D during the 1960s. But initially for a long period it was not very much acceptable to common Indian farmers. They used cheap labour to manage weed problems. In fact the organised tea planters started herbicide application with 2,4-D in the beginning; and paraquat thereafter. In field crop situations it gained importance with the increasing population pressure, more and more urbanisation, and higher input-depended intensive agriculture. Farmers are now aware of crop loss due to weed infestation. Weed management is a compulsory event today for them to raise a crop. The labour crisis is compelling farmers to move forward with chemical weed management. Within a very short span of time, herbicide use shore up by manifolds. Now, 60 herbicides of different modes of action are registered in our country. More than 700 formulations of herbicides are available in the market. Nowadays combination formulations of two different herbicides are also becoming popular amongst farmers for broad-spectrum weed control. Even, proposal for combination formulation of more than two active principles has been suggested to the Registration Committee to combat resistant weeds.



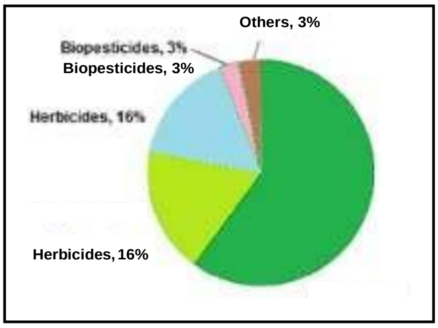


Fig. Losses caused by different pests **Fig. Crop protection market segments in India**

Source: Tata Strategic Management Group (2014) Source: Tata Strategic Management Group (2014)

The herbicide use, in comparison to industrialized countries, is significantly low in India till today. Albeit the crop loss is more due to the weed infestation than that caused by other pests (Fig 1.1), the use of insecticides takes the lion's share, around 65% , whereas, the use of herbicide is well around 16% (Fig. 1.2). Moreover, it was below 5% during 1970s and 1980s. If we consider the load of herbicides in Indian soil from the beginning, it is negligible in comparison to insecticides. But taking the lesson from industrialized countries, where the herbicide consumption is more than 65% of total pesticides, we should be alert and plan accordingly to minimize the toxicity due to herbicides in the future.

Characteristics of Weeds

A *<u>weed</u>* *is defined as a plant of its proper place or where it is not required.* A weed has more potential than the crop, compete with the crop, seed formation and distribution is before the seed and fruit production from the crop.

Here are the few characteristics which must be present in any plant to call them infestation and problematic for the crop (because there are some cropping systems such as relay cropping and intercropping where 2,3 crops are in the same field.

Weeds have several characteristics that are considered negative and as mentioned previously interfere. Below are some characteristics of weeds:

• Plants that produce an abundant of seed
• Plants that have an extensive root system or other vegetative structures that spread above or below the ground
• Plants that grow quickly
• Plants that can cause bodily harm to humans or animals
• Plants that can harbor diseases or insects that affect desired plants
• Plants that can produce chemicals that are toxic to surrounding plants
• Plants that can reduce crop growth or inhibit harvest

Weeds are plants first before they are determined to be weeds. As plants, they do have attributes that can be considered beneficial to the environment. They can help keep soil in place, provide a place for wildlife to live and to feed, and can be aesthetically pleasing. As they die, they can turn into beneficial organic matter. In some cases, they can also have nutritional benefits. In the case of companies like Spring-Green, weeds can provide business and employment opportunities.

Harmful and Benefical effect of weeds on ecosystem

Harmful effects

Weeds have serious impacts on agricultural production. It is estimated that in general weeds cause 5% loss in agricultural production in most of developed countries, 10% loss in less developed countries and 25% loss in least developed countries.

In India, yield losses due to weeds are more than those from pest and diseases. Yield losses due to weeds vary with the crops. Every crop is exposed to severe competition from weeds. Most of these weeds are self-sown and they provide competition caused by their faster rate of growth in the initial stages of crop growth. In some crops, the yields are reduced by more than 50% due to weed infestation. These loses caused by weeds in some of the important crops are given in the following table.

Loss in crop yields due to weeds			
Crop	Reduction in yields due to weeds (%)	Crop	Reduction in yield due to weeds (%)
Rice	41.6	Groundnut	33.8
Wheat	16.0	Sugarcane	34.2
Maize	39.8	Sugar beet	70.3
Millets	29.5	Carrot	47.5
Soybean	30.5	Cotton	72.5
Gram	11.6	Onion	68.0
Pea	32.9	Potato	20.1

- Weeds compete with crops for water soil, nutrients, light, and space, and thus reduce the crop yields. An estimate shows that weeds can deprive the crops 47% N, 42% P, 50% K, 39% Ca and 24% Mg of their nutrient uptake.
- Weeds are also act as alternate hosts that harbor insects, pests and diseases and other micro-organisms. Alternate hosts of some of the pest and diseases

Crop	**Pest**	**Alternate host**
Red gram	Gram caterpillar	*Amaranthus, Datura*
Castor	Hairy caterpillar	*Crotalaria sp*
Rice	Stem Borer	*Echinocholoa, Panicum*
Wheat	Black Rust	*Agropyron repens*
Pearl Millet	Ergot	*Cenchrus ciliaris*
Maize	Downy Mildew	*Sacharum spontaneum*

- Some weeds release into the soil inhibitors of poisonous substances that may be harmful to the crop plants, human beings and livestock. Health problems caused by weeds to humans.

Health problem	Weed
Hay fever and Asthma	Pollen of Ambrosia and Franseria
Dermotitis	Parthenium, Ambrosia
Itching and Inflammation	*Utrica sp*
African sleeping sickness	Brush weeds
Malaria, encephaliltisand filaria caused by mosquito	Aquatic weeds like *Pistia lanceolate, Salvinia auriculata*

- Weeds reduce the quality of marketable agricultural produce. Cotamination of weed seeds of *Datura, Argemone, Brassica* etc., is harmful to human health and weed seeds present in the produce cause odd odour sometimes.
- Weeds not only reduce yield but also interfere with agricultural operations. Weeds make mechanical sowing a difficult process and render harvesting difficult, leading to increased expenditure on labour, equipment and chemicals for their removal.
- In aquatic environment, weeds block the flow of water in canals, water-transport system and drainage system, rendering navigation difficult. The dense growth of aquatic weeds pollutes water by deoxygenating it and killing the fishes.
- Weeds are also a nuisance and a fire hazard along railway lines, roads, right-of- ways, airports, forest and industrial sites.

Beneficial Effects

Before making a decision on weed control and armed with information on the weed's ecology, we need to consider whether it performs some beneficial ecological role.

- does it reduce or enhance biodiversity
- does it provide useful structure or have a functional role
- does it disrupt or rehabilitate ecosystem processes
- does it disrupt or enhance soil and erosional processes.

Despite the negative impacts of some weeds, some plants usually thought of as weeds provide benefits. For instance, because weeds usually have very high rates of nutrient uptake they are adapted to take advantage of the brief pulse of nutrient release that accompanies the breakdown of organic matter when soil is disturbed. A very important function therefore is that they keep the nutrients in the system.

Some other beneficial ecosystem services may include:

- soil stabilization;
- help develop soil food web in disturbed soils;
- add organic matter;
- habitat and feed for wildlife;
- nectar for bees and butterflies;
- provide shelter for growing plants;
- aesthetic qualities.

We must therefore take a more holistic approach and consider those characteristics which make a weed useful in restoration processes.

CLASSIFICATION OF WEEDS

Out of 2, 50,000 plant species, weeds constitute about 250 species, which are prominent in agricultural and non-agricultural system. Under world conditions about 30000 species is grouped as weeds.

I. Based on life span

Based on life span (Ontogeny), weeds are classified as Annual weeds, Biennial weeds and Perennial weeds.

a. Annual Weeds

Weeds that live only for a season or a year and complete their life cycle in that season or year are called as annual weeds.

These are small herbs with shallow roots and weak stem. Produces seeds in profusion and the mode of propagation is commonly through seeds. After seeding the annuals die away and the seeds germinate and start the next generation in the next season or year following.

Most common field weeds are annuals. The examples are

a. Monsoon annual

Commelina benghalensis, Boerhavia erecta

b. Winter annual

Chenopodium album

b. Biennials

It completes the vegetative growth in the first season, flower and set seeds in the succeeding season and then dies. These are found mainly in non-cropped areas.

Eg. *Alternanthera echinata, Daucus carota*

(c) Perennials

Perennials live for more than two years and may live almost indefinitely. They adapted to withstand adverse conditions. They propagate not only through seeds but also by underground stem, root, rhizomes, tubers etc. And hence they are further classified into

i. **Simple perennials:** Plants propagated only by seeds. Eg. *Sonchus arvensis*

ii. **Bulbous perennials:** Plants which possess a modified stem with scales and reproduce mainly from bulbs and seeds. Eg. *Allium* sp.

iii. **Corm perennials**b Plants that possess a modified shoot and fleshy stem and reproduce through corm and seeds. Eg. *Timothy* (*Phleum pratense*)

iv. **Creeping perennials:** Reproduced through seeds as well as with one of the following.

a. **Rhizome:** Plants having underground stem – *Sorghum halapense*

b. **Stolon:** Plants having horizontal creeping stem above the ground – *Cynodon dactylon*

c. **Roots:** Plants having enlarged root system with numerous buds – *Convolvulus arvensis*

d. **Tubers:** Plants having modified rhizomes adapted for storage of food – *Cyperus rotundus*

II. Based on ecological affinities

a. Wetland weeds

They are tender annuals with semi-aquatic habit. They can thrive as well under waterlogged and in partially dry condition. Propagation is chiefly by seed. Eg. *Ammania baccifera, Eclipta alba*

b. Garden land weeds (Irrigated lands)

These weeds neither require large quantities of water like wetland weeds nor can they successfully withstand extreme drought as dryland weeds. Eg.*Trianthema portulacastrum, Digera arvensis*

c. Dry lands weeds

These are usually hardy plants with deep root system. They are adapted to withstand drought on account of mucilaginous nature of the stem and hairiness. Eg. *Tribulus terrestris, Argemone mexicana.*

III. Based on soil type (Edaphic)

(a) **Weeds of black cotton soil:** These are often closely allied to those that grow in dry condition. Eg., *Aristolochia bracteata*

(b) **Weeds of red soils:** They are like the weeds of garden lands consisting of various classes of plants. Eg. *Commelina benghalensis*

(c) **Weeds of light, sandy or loamy soils:** Weeds that occur in soils having good drainage. Eg. *Leucas aspera*

(d) **Weeds of laterite soils:** Eg. *Lantana camara, Spergula arvensis*

IV. Based on place of occurrence

(a) **Weeds of crop lands:** The majority of weeds infests the cultivated lands and cause hindrance to the farmers for successful crop production. Eg. *Phalaris minor* in wheat

(b) **Weeds of pasture lands:** Weeds found in pasture / grazing grounds. Eg. *Indigofera enneaphylla*

(c) **Weeds of waste places:** Corners of fields, margins of channels etc., where weeds grow in profusion. Eg. *Gynandropsis pentaphylla*, *Calotropis gigantea*

(d) **Weeds of playgrounds, road-sides:** They are usually hardy, prostrate perennials, capable of withstanding any amount of trampling. Eg. *Alternanthera echinata, Tribulus terestris*

V. Based on Origin

(a) **Indigenous weeds:** All the native weeds of the country are coming under this group and most of the weeds are indigenous. Eg. *Acalypha indica, Abutilon indicum*

(b) **Introduced or Exotic weeds:** These are the weeds introduced from other countries. These weeds are normally troublesome and control becomes difficult. Eg. *Parthenium hysterophorus, Phalaris minor, Acanthospermum hispidum*

VI. Based on cotyledon number

Based on number of cotyledons it possess it can be classified as dicots and monocots.

(a) Monocots Eg. *Panicum flavidum, Echinochloa colona*

(b) Dicots Eg. *Crotalaria verucosa, Indigofera viscosa*

VII. Based on soil pH

Based on pH of the soil the weeds can be classified into three categories.

(a) Acidophile – Acid soil weeds eg. *Rumex acetosella*

(b) Basophile – Saline & alkaline soil weeds eg. *Taraxacum sp.*

(c) Neutrophile – Weeds of neutral soils eg *Acalypha indica*

VIII. Based on morphology

Based on the morphology of the plant, the weeds are also classified in to three categories. This is the most widely used classification by the weed scientists.

(a) **Grasses:** All the weeds come under the family Poaceae are called as grasses which are characteristically having long narrow spiny leaves. The examples are *Echinocloa colonum, Cynodon dactylon.*

(b) **Sedges:** The weeds belonging to the family Cyperaceae come under this group. The leaves are mostly from the base having modified stem with or without tubers. The examples are *Cyperus rotundus, Fimbrystylis miliaceae.*

(c) **Broad leaved weeds:** This is the major group of weeds as all other family weeds come under this except that is discussed earlier. All dicotyledon weeds are broad leaved weeds. The examples are *Flavaria australacica, Digera arvensis, Tridax procumbens*

IX. Based on nature of stem

Based on development of bark tissues on their stems and branches, weeds are classified as woody, semi-woody and herbaceous species.

(a) **Woody weeds:** Weeds include shrubs and undershrubs and are collectively called brush weeds. Eg. *Lantana camera, Prosopis juliflora*

(b) **Semi-woody weeds:** eg.*Croton sparsiflorus*

(c) **Herbaceous weeds:** Weeds have green, succulent stems are of most common occurrence around us. Eg. *Amaranthus viridis*

X. Based on specificity

Besides the various classes of weeds, a few others deserve special attention due to their specificity. They are, a. Poisonous weeds, b. Parasitic weeds and c. Aquatic weeds.

a. Poisonous weeds

The poisonous weeds cause ailment on livestock resulting in death and cause great loss. These weeds are harvested along with fodder or grass and fed to cattle or while grazing the cattle consume these poisonous plants. Eg. *Datura fastuosa*, *D. stramonium* and *D. metal* are poisonous to animals and human beings. The berries of *Withania somnifera* and seeds of *Abrus precatorius* are poisonous.

b. Parasitic weeds

The parasite weeds are either total or partial which means, the weeds that depend completely on the host plant are termed as total parasites while the weeds that partially depend on host plant for minerals and capable of preparing its food from the green leaves are called as partial parasites. Those parasites which attack roots are termed as root parasites and those which attack shoot of other plants are called as stem parasites. The typical examples are;

1. Total root parasite – *Orabanche cernua* on Tobacco
2. Partial root parasite - *Striga lutea* on sugarcane and sorghum
3. Total stem parasite - *Cuscuta chinensis* on leucerne and onion
4. Partial stem parasite - *Loranthus longiflorus* on mango and other trees.

c. Aquatic weeds:

Unwanted plants, which grow in water and complete at least a part of their life cycle in water are called as aquatic weeds. They are further grouped into four categories as submersed, emersed, marginal and floating weeds.

1. **Submersed weeds:** These weeds are mostly vascular plants that produce all or most of their vegetative growth beneath the water surface, having true roots, stems and leaves. Eg. *Utricularia stellaris, Ceratophyllum demersum.*

2. **Emersed weeds:** These plants are rooted in the bottom mud, with aerial stems and leaves at or above the water surface. The leaves are broad in many plants and sometimes like grasses. These leaves do not rise and fall with water level as in the case of floating weeds. Eg. *Nelumbium speciosum, Jussieua repens.*

3. **Marginal weeds:** Most of these plants are emersed weeds that can grow in moist shoreline areas with a depth of 60 to 90 cm water. These weeds vary in size, shape and habitat. The important genera that comes under this group are; *Typha, Polygonum, Cephalanthus, Scirpus, etc.*

4. **Floating weeds:** These weeds have leaves that float on the water surface either singly or in cluster. Some weeds are free floating and some rooted at the mud bottom and the leaves rise and fall as the water level increases or decreases. Eg. *Eichhornia crassipes, Pistia stratiotes, Salvinia, Nymphaea pubescens*.

Reproduction in Weeds

- **Weeds most often reproduce by seed.**
- Some weeds reproduce through vegetative means.
  - new individuals formed from multicellular structures of a single plant.
  - vegetative reproduction is a trait that is shared by 60% of the world's worst weeds.

  reproduction by vegetative methods makes weed control extremely difficult
- An understanding of a weed's **breeding system**, **methods of propagule dispersal**, and **life form** is important.
- **These attributes can be used to predict population spread and longevity.**
- They can also be used to predict genetic diversity within and among populations.
- The more genetically diverse a population:
  - the more it is buffered from management strategies
  - more likely that individuals are present that can adapt to the strategy.

Breeding Systems in Plants

- Outcrossing
- Self pollination
- Clonal
- Mixed mating

Breeding systems for many weeds are not well known

Outcrossing in Weeds

- The gametes that form the zygote are genetically dissimilar.
  - Self-incompatibility may be involved.
  - Outcrossing may occur between closely related individuals.
  - Inbreeding depression
- Leads to more diversity with in a population.
- Leads to less diversity among populations.
- Populations from different geographies are not very specialized.
- At low densities there may not be enough pollen to produce the full potential of seed.

- If the species is an obligate outcrosser, at least two plants are required to start a new population.

- **Self-pollination in Weeds**

- The gametes that form the zygote are genetically very similar.
- Leads to less diversity <u>within</u> a population.
- A population can be relatively homozygous.
- Leads to more diversity <u>among</u> populations
- Populations from different geographies can be very specialized.
- If the species can self pollinate, only one plant is required to start a new population.

- **Vegetative Propagation in Weeds**
- **Offspring are genetically identical to the maternal parent.**
- Within population diversity can be hard to predict.
  - is it a mixture of clones?
  - is it only one clone?
  - mutations are preserved.
- **Among population diversity also can be hard to predict.**
  - It only takes one plant to start a new population

Mixed Mating Systems in Weeds

- May be the most common method in weeds.
- The distribution of heterozygotes, homozygotes, and clones depends on the proportion in the original population.
- Some common combinations
  - Facultative selfing in an outcrossing species
  - Predominately selfing with a low level of outcrossing
  - Outcrossing with clonal capacity
  - Facultative apomixis

- **Apomixis**
- **An asexual form of reproduction where a seed is formed without fertilization.**
  - Somatic cells or gametes in the mother plant develop into an embryo.

- Examples - Hawkweed (*Hieracium* spp.), dandelion (*Taraxacum*), some citrus (*Citrus*), blackberries (*Rubus* spp.), and Kentucky bluegrass (*Poa pratensis*)

- **Advantages to Seed Production**
- **Much more genetic diversity.**
- Seed are a complete package.
  - Preserved in time.
  - Preserved against harsh environments.
  - Seed are easily dispersed.
  - Many seed are produced.

  Depends on the presence of competitors

Vegetative Reproduction

- Many types of vegetative propagules are known.
- Vegetative reproduction occurs through modification of a stem that grows horizontally.
  - underground stems or rhizomes
  - roots
  - aboveground stems or stolons
  - corms, bulbs, and tubers (storage for carbohydrates)

  Advantage

- **Can create clones of a successful genotype and provide genetic stability.**
- Can establish a new population from one plant or propagule.
- Storage organs propagate rapidly and in large quantities.
- Usually difficult to control.

Dissemination

- A plant seed is a unique genetic entity, a biological individual. However, a seed is in a diapause state, an essentially dormant condition, awaiting the ecological conditions that will allow it to grow into an plant, and produce its own seeds.
- Seeds must therefore germinate in a safe place, and then establish themselves as a young seedling, develop into a juvenile plant, and finally become a sexually mature adult that can pass its genetic material on to the next generation.
- The chances of a seed developing are generally enhanced if there is a mechanism for dispersing to an appropriate habitat at some distance away from the parent plant.

- The reason for dispersal is that closely related organisms have similar ecological requirements. Obviously, competition with the parent plant will be greatly reduced if its seeds have a mechanism to disperse some distance away. Their ability to spread and remain viable in the soil for years makes eradication nearly impossible.
- Seeds have no way to move on their own, but they are excellent travellers. Plants have evolved various mechanisms that disperse their seeds effectively.
- Many species of plants have seeds with anatomical structures that make them very buoyant, so they can be dispersed over great distances by the winds.
- In the absence of proper means of their dispersal, weeds could not have moved from one country to another.
- An effective dispersal of weed seeds and fruits requires two essentials a successful dispersing agent and an effective adaptation to the new environment.

There are two ways of looking at weed seed dispersal:

- The expanding range and increasing population size of an invading weed species into a new area
- The part of the process by which an established and stabilized weed species in an area maintains itself within that area Dissemination includes two separate processes. They are dispersal (leaving mother plant) and post-dispersal events (subsequent movement). Dispersal of seed occurs in 4 dimensions viz.

1. Length
2. Width: Land/habitat/soil surface area phenomena
3. Height : soil depth, in the air
4. Time: shatters immediately after ripening (or) need harvesting activity to release seed

Dormancy in weeds and its types

Definitions

- **Dormancy**: 1. A state in which viable seeds (or buds; spores) fail to germinate under conditions of moisture, temperature and oxygen favorable for vegetative growth (Amen, 1968); 2. A state of relative metabolic quienscence
- **Seasonal dormancy**: in an environment in which favorable growth conditions are seasonal, dormancy is usually clocked by solar rhythm; consequences to the population: predictive
- **Opportunistic dormancy**: when there is only a small seasonal element in the occurrence of favorable conditions dormancy tends to be both imposed and released by the direct experience of the unfavorable or favorable conditions; consequences to the population: responsive
- **Innate dormancy**: the condition of seeds as they leave the parent plant, and is a viable state but prevented from germinating when exposed to warm, moist aerated conditions by some property of the embryo or the associated endosperm or maternal structures
- **Induced dormancy**: is an acquired condition of inability to germinate caused by some experience after ripening; in the opportunistic dormancy category
- **Enforced dormancy**: is an inability to germinate due to an environmental restraint: shortage of water, low temperature, poor aeration, etc.; in the opportunistic dormancy category

Dormancy backround concepts

1. Dormancy occurs during periods of unfavorable conditions; is more resistant to environmental hazards
2. Dormancy can be seen as "dispersal in time"
3. Dispersal phase usually dormant; dehydrated seeds weight less (esp. wind dispersal) and are metabolically slower
4. Dormancy:
   a. rhythmic adaptation of weeds to the temporal rhythms in the environment
   b. strategic alternative to dispersal

Seed-Environment interactions: Seed dormancy a product of the interaction of the seed (embryo, envelopes like a seed coat, seed food reserves like the endosperm or cotyledons) and the environment (temperature, gases, water, light, soil, temperature)

However, based on the mechanism that causes dormancy, the following types are
well recognized to occur in weeds:
1-Physiological mechanism of dormancy
2-Ecological or demographical consequences of dormancy
Both are important to understand the evolutionary adaptations that weed seeds have developed in the agricultural environment.
A) Physiological mechanism of dormancy
This dormancy includes the following three types.

Innate Dormancy

Incomplete development

- Innate dormancy conferred by the fact that the process of growth of an embryo to a stage fit for germination has not been completed while the the embryo was still borne on the parent plant, it is shed morphologically incomplete
- Example: *Heracleum sphondylium*: development of embryo continues at the expense of extra-embryonic food reserves for several months after seed is shed
- This process imposes a necessary time lag between dispersal and germination

Control by a biochemical trigger

1. A biochemical process may need to be stimulated before the germination process can begin

2. Often this trigger is a seasonally related stimulus which can switch on germination at an adaptively appropriate time of year

3. Cues and triggers:

- Cues and triggers involved in breaking innate dormancy do not produce a clear "all or nothing" effect: only a portion of the seed germinate at one time; a spectrum of requirements by seeds in a single sample which may reflect:
  -different genotypes
  -different maternal influences
  -different ages and ripening conditions (influence of different environmental conditions at different times during reproductive phase, in same plant: Cavers)
- Light and phytochrome
  1. Example *Betula pubescens* (UK)
  a. require light and long days for germination
  b. length of dark period critical: germination declines with increasing dark period length
  c. temperature dependence complicated light dependence
  -at 20C light dependence lost
  -with chilling treatment light dependence lost
  2. Several other species follow variations on this same theme: e.g. many dicot weeds
- Temperature: chilling or flucuating temperature-
  example: *Papaver* spp.: diurnal flucuation between 10 and 30C breaks dormancy; occurs in upper layers of UK soils in April and May, fixes time of germination
- Nitrate ion: NO_3^-
  -nitrate concentration of the soil solution often rises quite sharply as the soil temperature increases in the spring
  -stimulation of *Chenopodium album* seed germination in the field, and several other species, stimulated by nitrate
- Germination stimulants
  -e.g. ethanol, anesthetics, etc.
  -[ecological, agricultural relevance?]

Removal of an inhibitor: Two categories of phenomena:

- Triggering of biochemical process which destroys a germination inhibitor: breakdown process of inhibitor which occurs within the tissues of the seed
- Physical leaching, or removal of the source of, and inhibitor: leaching or destruction of inhibitor by an external agent

Physical restriction of gas exchange and growth

1. Physical restriction of water and gas

- Impermeable (or relatively impermeable) seed or fruit coat may prevent water or gas uptake by seed and prevent germination until physical damage occurs to this barrier -example: *Avena fatua* (wild oat) seed dormancy broken easily by pricking pericarp
- Common innate dormancy in species inhabiting sand dunes; abrasion by sand
- Scarification: seeds that require abrasion tend to break dormancy at different times rather than in a sudden flush
  -example: *Avena fatua* (wild oat) seed dormancy broken easily by pricking pericarp
  -example: *Abutilon theophrasti* hard seed coat: germination broken readily with treatments cracking hard seed coat (50C for 15 minutes; 10-15 minutes in sulfuric acid); hard seed coat confers very long dormancy and viability in soil seed bank

2. Dormancy caused by mechanical restriction of growth by embryo coverings (pericarp, testa, perisperm, endosperm) -example: cocklebur: upper seed (of two in capsule) radicle is restricted, insufficient thrust to rupture testa and germinate

Genetic control of innate dormancy

- Innate dormancy appears to be under strict and simple genetic control; often modified by maternal effects (i.e. endosperm effects from mother; maternal origin of ovary)
- Commercial crop seed have lost dormancy present in wild relatives in process of domestication; some dormancy left as protection from precocious germination of crop seed while still in inflorescence (?) in wet weather near harvest time
- Genetically controlled polymorphism: distinctly different dormancy genotypes -example: *Spergula arvensis*: 3 different seed coats, each control different levels of seed dormancy
  -example: *Nicandra physaloides*: presence or absence of isochromosomes determines whether the seed is non- dormant (2n = 20) or dormant (2n = 19)

Somatic polymorphism and innate dormancy

Somatic polymorphism: Production of seeds of different morphologies or behavior (phenotypes) on different parts of the same plant; not a genetic segregation but a somatic differentiation

Somatic polymorphism represents an allocation of different fractions of the seed output of a plant to different ends

- Adaptive advantage to producing seed on one plant with different qualities
- Common adaptation limited to weedy species usually

- Seed dormancy somatic polymorphism is common in weedy species of Gramineae, Compositae, Chenopodiaceae and Cruciferae families

Somatic polymorphism allows sensitive adjustment to environment in the number of morphs it produces

- A quality lacking in genetic polymorphisms: continuum of responses, not just a few genetic alternatives
- Proportion of morphs can be subtly and directly altered by environmental conditions experienced by the parent plant

Seed produced on same plant can have range of dormancy; mechanism proposed:

- Water stress in mature leaves plus short days may induce abscissic acid production
- ABA may have an effect on developing seeds as they differentiate histologically in developing seed
- Differences in dormancy in seed may be a function of water stress at time of seed development
- Germinability of seeds as a function of maternal environment (Gutterman, Y. 1978. Acta Horticulurae 83:41-55)

Seed and dormancy polymorphisms are so common amongst weed species that it is dangerous to ascribe one set of dormancy mechanisms or germination breaking requirements to any one species

- 1. example: *Rumex crispus* (curled dock)
  -progeny of individual plants vary enormously in ability to germinate in darkness or at common temperature
  -variation is greater between plants than between habitats, no one germination response
- Example: *Xanthium* spp. (Cocklebur);
  -seed borne in pairs in capsule: large and small seed dispersed together
  -upper seed in capsule usually dormant, lower germinates first due to differences in testa permeability to water entry, leaching of endogenous germination inhibitors
  -dormancy breaking requirements different for 2: 12 month difference insurance second will become established if first year unfavorable
- Example: *Avena fatua* (wild oat), and *Avena ludoviciana*
  -grains borne on different parts of the spikelet have different germination requirements
  -first grain of spikelet lacks dormancy, remainder have deep dormancy
- Example: Compositae germination behavior differentiated by seed size, seed formed in ray versus disc flowers
- Example: *Chenopodium album* (common lambsquarters) may produce 4 different kinds of seed on same plant
  -two color categories: brown and black; two seed coat categories: reticulate and smooth
  -brown: thin-walled, larger, germinate quicker than black, even at low temperatures; killed by winter, but if they survive have the capacity to produce very large plants with high reproductive output; only 3% of seed on a plant; among the first to be produced by a plant
  -black: require cold treatment, nitrate to break dormancy
  -ratio of brown:black govered by environmental conditions

Example: common purslane seed varied from nondormant to dormant on same plant

Enforced Dormancy

- **Imposed dormancy**: state of seed dormancy maintained by the absence of necessary conditions for germination
  -E.g. shortage of water, temperature, unfavorable soil atmosphere, etc.
  -E.g. seed buried deeply in soil by tillage, etc., commonly has enforced dormancy
- Carbon dioxide narcosis in soils common factor in enforced dormancy; e.g. high respiration sites in soil elevate CO_2 (seed respiration, soil microorganisms)
- Lowered oxygen tension in the soil also important here; e.g. severe oxygen starvation in waterlogged or compacted soils
- Temperate agricultural regions: low temperature enforces dormancy

Induced Dormancy

A seed has acquired dormancy which is not innate and which does not require continued enforcement

CO_2 narcosis: example: *Brassica alba* dormancy induced by high CO_2 treatment

Drought induced dormancy: example: observed especially in Leguminosae:

- ilum acts as a hygoscopically activated valve
- when air is dry the hilum valve opens and allows water loss from seed
- in wet air it closes,
- embryo progressively dries to a value equal to that of the driest environment it experienced
- hard seed dormancy only broken by seed coat scarification
- white and red clover seed

Seed burial induction of requirement for light to germinate

- collected seed from soil in dark after burial treatment
- later seed of many species (buckhorn plantain, corn spurry, field poppy) tested had light requirement for germination which was not needed when freshly harvested

Cold treatment induced light requirement for germination of *Stellaria media* (Chickweed); one way autumn shed seed acquire light requirement by spring

High temperature exposure of imbibed seeds coupled with restriction of oxygen availability induced dormancy

Crop-Weed competition

Competition is nothing but the struggle for existence and superiority. Competition exerts a powerful force in the plant community, irrespective of the mechanism, tending towards limitation or extinction of the weaker competitors. Competition is maximum when available resources for crop growth become limited.

Competition is a negative interaction where individuals make simultaneous demands that exceed limited resources and, while both suffer, one individual suffers less.

So, crop weed competition indicates competition between crop and weed in a natural ecosystem in response to resources struggle for their existence and superiority.

Crop weed competition occurs in two broad aspects:

1. Direct competition- for nutrient, moisture, light and space
2. Indirect competition- through exudation and / or production of allelopathic chemicals.

By and large, weeds appears much more adapted to agroecosystem than our present day crop plants.

Components of the overall competitive effect

In an infested field it is possible to identify different components of the overall competitive effect:

- Intra-specific competition between plants of the cultivated species;
- Inter-specific competition between plants of the cultivated species and weed species;
- Inter-specific competition between plants of the different weed species;
- Intra-specific competition between plants of the same weed species.

Competition between weeds and crops is expressed by altered growth and development of both species. Inter-specific competition occurs when two or more species coexist in time and space and simultaneously demand a limited resource. Intra-specific competition occurs when two or more plants of the same species coexist in time and space and simultaneously demand a limited resource.

Competition for nutrients

Plants compete mostly for nitrogen, phosphorus and potassium (but there are many others). Phosphorus is usually the most limited nutrient in aquatic ecosystems. Nitrogen is usually the most limited nutrient in terrestrial habitats. Potassium is often overlooked but some terrestrial weeds can grow well in K-rich soils. Approximately competition for nutrients constitutes an important aspect of weed crop competition. Weeds usually absorb mineral nutrients faster than many of our crop plants and accumulate them in their tissue in relatively large amounts.

Table: Kilograms of Nutrients Required to Produce Equal Amounts of Dry Matter

Plant	Nitrogen	Phosphorus
Wheat	5.5	1.2
Lambrushquarter	7.6	1.6
Pig weed	5.1	1.4

- Species of *Amaranthus*, for example, often accumulate over 3% N in their dry matter.
- *Chenopodium* and *Portulaca spp*. are likewise potassium lovers with over 1.3% K2O in their dry matter.
- Nutrient removal by weeds during the first 30 days of maize growth was 59 kg N, 10 kg P and 59 kg K per hectare, which was 7-10 times more than the nutrient removal by the crop
- Weed posses not only a capacity for heavy nutrient absorption and accumulation but also gather tremendous quantities of dry matter.

Competition for moisture

Competition for water occurs below ground between roots. The ability to absorb water is related to rooting volume. However, not only are the dimensions (breadth and depth) of rooting zones important: so is the degree of water extraction.

In general, for producing equal amounts of dry matter, weeds transpire more water than do most of our crop plants. In weedy fields, the soil moisture may be exhausted by the time the crop reaches the fruiting stage, which is often the peak. The consumptive use of water of a common weed *Chenopodium album* as 550 mm against 479 mm for wheat crop itself. It is because weed can remove moisture from deeper depth of soil than crops.

Table: Water Required to Produce One Pound of Dry Matter

Plant	Litres of water
Wheat	227
Lambrushquarter	300
Corn	159
Pigweed	132-139

Competition for light

Although it varies in duration, intensity, and quality, light regulates many aspects of plant growth and development. Neighboring plants may reduce light supply by direct interception: shading. Leaves are the site of light competition. Whenever a leaf is shaded by another, there is competition for light.

Light competition is most severe when there is high fertility and adequate moisture because plants grow vigorously and have larger foliar areas. Plants with large leaf area indices (LAI) have a competitive advantage with plants with smaller leaf areas.

Both light quality and quantity are important aspects of competition. Since the presence of dense leaf canopies reduces the quantity and quality of light available to weeds, competition for light is greatest when plant density is highest. Plant height defines an effective component of the competitive struggle for light. It becomes most important element of weed crop competition when moisture and nutrients are plentiful, and weeds have an edge over crop plants in respect of height. Light competition may commence very early in the crop season if a dense weed growth smoother the crop seedlings. Once a plant is shaded by another plant, increased light intensity cannot benefit it.

Critical period of weed growth

Critical period of weed growth can be defined as that shortest time span in the ontogeny of crop growth when weeding with result in highest economic returns. The crop yield level obtained by weeding during this short span should provide crop yield sufficiently close to that obtained by the full crop season freedom from weeds. A fundamental principle of plant ecology is that early occupants on a soil tend to exclude the later ones.

- On the basis of the plant ecology, crops required a weed free respite during the first one-forth to one-third of its growing period.
- Sharma *et al.* (1977) found that in direct seeded rice, the critical weed competition period occurred 10-20 days after crop emergence. For the transplanted rice the critical periods of weed crop competition were identified. These were (i) 4-6 weeks after transplanting and (ii) during the 12th weeks of crop growth.
- In maize for example, during the first 2-3 weeks of emergence, weeds often completed 15- 18% of their total growth, while maize put up only 2-3% of growth. Such observations have provided a basis in favour of early season weeding to harvest acceptable yields.
- 4 to 16 weeks period after planting sugarcane critical for competition weeds.
- In potato, weeding was found most essential between 2 and 4 weeks after planting. Delayed weeding caused considerable shrinkage in tuber yields

Table: Crops with an Apparent Critical Period for Weed Competition

Crop	Weed-free weeks required	Weeks of competition tolerated
Maize	3-5	3-6
Rice	4-6	4-9
Soybean	2-4 after planting	4-8 after planting
Potato	4-6	4-9

Factors affected weed crop competition

Competition depends on four interrelated factors-

A. **Timing of weed emergence:** The first plant that effectively obtains water, nutrients and sunlight from a site and becomes established at that site has distinct competitive advantages over plants that develop later. The effect of a weed competition is greatest when the crop is young, since this is the stage which plant growth is inhibited most by inadequate light, water and nutrients. Crop yields are much more reduced by early season weed competition than by later season competition.

B. **Growth form:** Growth form is manifested in two major parts i.e.,

- **Growth habit:** Extent of root development, height, leaf area, amount of branching
- **Growth rate:** Those which can develop canopy very rapidly over another, has definite advantage of shading over the second plant communities.

C) **Weed Density:** The numerical superiority that weeds exhibit greatly reduces the availability of water, nutrients and light to crop plants and accounts for much of what we consider to be weed competition. Increase in crop population density distributes available resources among the crop community, but increase in weed population diverts available resources from the crop communities. For example: 1 kg increase in weed dry matter = 1 kg loss in crop dry matter. Weed density is generally higher in distributed or agricultural soil than in undistributed soils.

D) **Duration of weed growth:** The duration of weed growth is equally important with all other factors. If weeds are allowed to grow for an extended period crop yield may be drastically reduced. Weeds that are not controlled within 2-3 weeks of emergence usually affect crop yield. This is particularly important for upland rainfed crops i.e. aus rice, jute etc. In most crops weed infestation during the first 3-8 weeks is very critical which is termed as "Critical period" of weed infestation. Crop fields must be kept weed free during this period.

E) **Characteristics of Weed species:** Weeds differ in their ability to compete with crops at similar density levels. This is primarily because of differences in their growth habits and to some extent in the allelopathic effect they may exert on the germination and growth of neighbouring crop plants. Zimadahl and Fertig (1967) found *Brassica spp*. (Wild mustard) reduced the sugarbeet yield much more than *Setaria glauca* (Yelow foxtail). In dry areas perennial weeds like *Cirsium arvense* (Canada thistle) and *Convolvulus arvensis* (Bindweed) have been found more competitive than the annual weed species because of their deep roots and early, heavy shoots growth.

F) **Characteristics of crop species:** Crops and their varieties differ in their competing ability with weeds. Several researchers are available to differentiate crop species and varieties in this respect. Among winter grasses, for example, the decreasing order of weed competing ability is as barley, rye, wheat and oat. High tolerance of barley to competition from weeds is assigned to its ability to develop more extensive roots during its initial three weeks growth period than the other grains.

- ***Boro* Rice:** Do not appreciably suffer from weed competition due to standing water throughout the growth period, particularly during the critical periods of weed infestation, i.e., seedling establishment, panicle initiation, flowering stages etc.
- ***Aman* Rice:** Do not usually suffer at earlier stages until warming of soil temperature in later growth stages, which causes weeds to germinate or being rapid growth.
- ***Aus* Rice:** Most sensitive to weed infestation. Suffers weed competition from very beginning. Cost of production is high due to intensive weed management. Entire crop failure is possible if weed control is not done timely and properly.
- **Onion:** Slow growing, never forms a canopy, poor competitor to late germinating weeds. Critical period of crop-weed competition was found to be 20-60 DAT. Early infestation of weeds in onion is one of the major constraints limiting the establishment of the crop and thereafter its production.
- **Field Pea:** The critical period for crop-weed competition was observed to be between 30–60 days after sowing when the crop should be kept free from weeds to prevent the potential yield loss and to economize weeding in fieldpea. (Prakash and Srivastava, 2007).

List of characteristics associated with competitive plants

Shoot characteristics

- Rapid expansion of tall, foliar canopy
- Horizontal leaves under overcast conditions and obliquely slanted leaves (plagiotropic) under sunny conditions
- Large leaves
- A C4 photosynthetic pathway and low leaf transmissivity of light
- Leaves forming a mosaic leaf arrangement for best light interception
- A climbing habit
- A high allocation of dry matter to build a tall stem
- Rapid extension in response to shading

Root characteristics

- Early and fast root penetration of a large soil area
- High root density/soil volume
- High root–shoot ratio
- High root length per root weight
- High proportion of actively growing roots
- Long and abundant root hairs
- High uptake potential for nutrients and water

ALLELOPATHY or TELETOXY

The term **allelopathy** was introduced by **Molisch** (1937). Plants growing in the community produce and release numerous secondary metabolites, many of which are capable of initiating chemical warfare among the neighboring plants.

This phenomenon of one plant having a detrimental effect on another through the production and release of toxic chemicals has keen termed 'allelopathy'.these chemicals are called allelo chemicals. *Parthenium* daughter plants exhibiting teletoxy to its parent plants is known as autotoxy. **Allelopathic chemicals** – are largely derivatives of b**enzoic acids**, **cinnamic acids, phenolic acids, coumarins, hydroquinones, benzoquinones,**

The word allelopathy is derived from Greek – allelo, meaning each other and patho, an expression of sufferance of disease. These chemicals **inhibit the seed germination** of small grains with *Cyperus rotundus* extracts .Growth of wheat plants by avena fatua and Phalaris minor extracts.**Reduction of germination** of cabbage and egg plant by *Amaranthus retroflexus.* **Inhibition of the growth** of many agronomic plants by *Parthenium spp* extracts.

Chemicals released in the form of

Vapour (released from plants as vapour): Some weeds release volatile compounds from their leaves. Plants belonging to labiateae, compositeae yield volatile substances.

Leachates from the foliage: From *Eucalyptus* allelo chemicals are leached out as water toxins from the above ground parts by the action of rain, dew or fog.

Exudates from roots: Metabolites are released from *Cirsium arvense* roots in surrounding rhizosphere.

Decomposition products of dead plant tissues and warn out tissues

The production of allelo chemicals is influenced by the intensity, quality and duration of light Greater quantity produced under ultra violet light and long days. Under cropped situation low allelo chemicals. Greater quantities are produced under conditions of mineral deficiency, drought stress and cool temperature more optimal growing conditions.

Allelopathic control of certain weeds using Botanicals

For instance Dry dodder powder has been found to inhibit the growth of water hyacinth and eventually kill the weed. Likewise **carrot gross** powder found to detrimental to other aquatic weeds. The presence of m**arigold** (*Tagetes erecta)* plants exerted adverse allelopathic effect on *parthenium* spp growth. The weed coffeesena (*Cassia spp)* show suppressive effect on *parthenium*. The **eucalyptus** tree leaf l**eachates** have been shown to suppress the growth of nut sedge and bermuda grass.

Allelo chemicals are produced by plants as end products, by-products and metabolites liberalized from the plants

1) Allelopathic effects of weeds on crop plants.

Maize

- Root exudates of Canada thistle (*Cirsium sp*.) injured oat plants in the field.
- Root exudates of Euphorbia injured flax. But these compounds are identified as parahydroxy benzoic acid.

- Leaves & inflorescence of *Parthenium* sp. affect the germination and seedling growth
- Tubers of *Cyperus esculentus* affect the dry matter production
- Quack grass produced toxins through root, leaves and seeds interfered with uptake of nutrients by corn.

Sorghum

- Stem of *Solanum* affects germination and seedling growth
- Leaves and inflorescence of *Parthenium* affect germination and seedling growth

Wheat

- Seeds of wild oat affect germination and early seedling growth
- Leaves of *Parthenium* affects general growth
- Tubers of *C. rotundus* affect dry matter production
- Green and dried leaves of *Argemone mexicana* affect germination & seedling growth

Sunflower

- Seeds of *Datura* affect germination & growth

2) Effect of weed on another weed

- **Thatch grass** (*Imperata cylindrica*) inhibited the emergence and growth of an annual broad leaf weed (*Borreria hispida*).
- Extract of leaf leachate of decaying leaves of *Polygonum* contains flavonoides which are toxic to germination, root and hypocotyls growth of weeds like *Amaranthus spinosus*
- Inhibitor secreted by decaying rhizomes of *Sorghum halepense* affect the growth of
  - *Digitaria sanguinalis* and *Amaranthus* sp.
- In case of *parthenium*, daughter plants have allelopathic effect on parent plant.
  - This is called AUTOTOXY

3) Effect of crop on weed

- Root exudates of wheat, oats and peas suppressed *Chenopodium album*. It increased catalase and peroxidase activity of weeds and inhibited their growth.
- water extract of wheat straw reduces growth of *Ipomea* & *abutilon.*

4) Stimulatory effect

- Root exudates of corn promoted the germination of *orbanchae minor*; and *Striga hermonthica* .Kinetin exuded by roots sorghum stimulated the germination of seeds of *stirga asisatica*
- Strigol – stimulant for witch weed was identified in root exudates from cotton.

Principles of weed management

Weeds are very important factors in crops production.

What is your experience with weeds?

- Weeds compete with your crops for light, moisture, nutrients, and space. They are very aggressive in doing so. And so, they can deprive your crops of all these resources for a good yield.
- They can reduce the yield of the crop through the release of toxic substances which inhibit crop growth. This is allelopathy. Uncontrolled weed infestation can lead to a 95% yield loss in cassava, 40% in maize and 53% in cowpea, soybean and pigeon pea. Weeds serve as hosts for diseases and insects.
- They increase production and processing costs.
- Severe weed infestation can reduce the quality and value of the produce.

What are the Principles of weeds control and management?

The principles of weed control are the basis for the development of the various methods of weed control and management. There are a number of ways to control weeds. They are based on these principles.

➢ Prevention

Stop weeds from contaminating an area. As much as possible, this preventive measure is the most effective means of weed control. You can achieve this by;

1. Making sure you do not carry new weed in contaminated crops seeds, feed and/or machinery.
2. Preventing weed from producing seeds
3. Preventing the spread of perennial weeds that reproduce vegetatively.

These measures can greatly reduce weed problems.

➢ Control

This is the process of limiting weed infestation. And also minimizing competition with crops. When weeds are limited they have minimal effect on crop growth and yield. However, you can apply this principle when the problem of weed exists. It is not preventive.

➢ Eradication

This involves complete removal of all living weed plants including their vegetative propagules and seeds. This is a more difficult approach that preventive and control. It is justified only for the elimination of serious weeds in a limited area. Example, perennial weed in a small area of a field.

(Important)

In weed control and management, is always better to prevent than to control. But, you can control if weeds arrive without notice. Also, when they are present before you can prevent them. Prevention and eradication require long-term thinking and planning.

So, every single method or combinations of methods of weed management will seek to either prevent, control or eradicate. You can also manage weeds with a combination of principles.

Methods of weeds control and management

We use these methods based on the principles of weed control. You can use one or a combination of methods to either prevent, control or eradicate weeds.

- **Cultural**

Cultural weeds control uses a technique that requires that you maintain a good field condition. So that weeds do not establish or increase in number. Examples are the adoption of crop rotation, mulching, cover cropping, avoiding overgrazing and maintaining good soil fertility.

- **Mechanical/Physical**

In mechanical weeds control, we use farm equipment to control the weeds. The mechanical weed control techniques we often use are tillage (involving ploughing and harrowing), mulching, hand removal, burning and mowing.

- **Biological**

Biological weeds control involves the use of natural enemies of weed plants. This controls the germination of weed seeds or the spread of established plants. This is fast becoming a popular method. Examples include sheep to control tansy ragwort or leafy spurge, cinnabar moth and the tansy flea beetle to control tansy ragwort. Further, the chrysolina beetle is used to control St. John's Wort, and the use of goats to control weeds on rangeland.

- **Chemical**

This refers to any technique that involves the application of an agrochemical (herbicide) to weeds or soil to control the germination or growth of the weed species. Chemical control of weed is the commonest among farmers in this region. Common examples of chemicals used to control weeds in forages are 2,4-DB; (*Dichlorophenoxyacetic* acid), EPTC (selective herbicide), bromoxynil, paraquat (gramoxone) and glyphosate.

Physical and Cultural Weed Control

The methods of physical weed control to be discussed are the use of fire, water management, mulching and solarization.

Fire has been used for many years as a method of destroying unwanted vegetation in noncrop as well as various cropping situations. Generally, the heat from flaming causes the cell cap to expand, rupturing the cell walls. There is also a coagulation of protoplasm and an inactivation of enzymes resulting from the high temperatures. The thermal death point for most plant cells is between 113 and 131°F. However, most dry seeds are more tolerant of high temperatures than are plant tissue and most often require prolortged exposures to effectively limit their germination. Nonselective burning has no distinction as to just eliminating the weeds; all plants contacted are killed. Field burning is one example of nonselective burning. In grass seed production, field burning removes the straw and stubble, where diseases flourish, as well as kill 95-99% of the weed seeds at the soil surface. Rangelands can be modified with fire to reduce certain weed pests and encourage more palatable types of vegetation.. Control burns have also been somewhat successful in forest lands to eliminate the understory and reduce the threat of uncontrolled fire from excess combustible fuel. However, effective kill of certain shrub under- stories by fire has at times been erratic and less effective than chemical control.

The parasitic weed dodder in alfalfa would be an example for the use of nonselective burning. In this situation the alfalfa would also be killed in small patches along with the dodder to prevent further infestations. Broomrape in crops such as tomatoes can also be controlled by the use of fire. Here the crop is also destroyed in the immediate area, but more importantly, the weed is killed, eliminating further spreading. A directed flame or a hooded burner is used where the crop is to be protected from injury. Crops in which this technique is used includes cotton, corn, soybeans, grain sorghum, castor beans and sesame. Proper timing is essential for greatest weed kill and minimal injury to the crop. Generally, best weed control is obtained when the weeds are 1-2 inches tall. In cotton, flaming can begin when the stems are 3/16 inch in diameter at ground level. By this time the cotton plant is about 8 inches tall. Timing is also necessary for selective burning in corn, where it should not be flamed when the crop is between 2 and 12 inches high. Corn less than 2 inches tall can be flamed since the growing point is still underground. Corn taller than 12 inches will not be injured by flaming small weeds at the base of the plants. Fire is just one method of weed control. It has advantages such as the elimination of dead vegetation, reducing the density of next season's weeds and has no "carry-over" as do some herbicides. Drawbacks to the use of fire include the lack of killing subsurface weed seeds, possible crop injury and contributing to air pollution. The use of fire to control weeds would probably be most useful in conjunction with other methods of weed control.

Proper utilization of water will have a definite impact on many weeds, both annual and perennial. As with agricultural crops, weeds also require a given set of conditions for optimum growth and development. Water manage- ment can play a vital role in reducing specific weed problems. Flooding had its beginnings in the culture of rice. It was found that flooding the land with 6 to 10 inches of water for 3 to.8 weeks during the summer controlled weeds such as barnyardgrass, signalgrass, sprangletop, hemp sesbania, and northern jointvetch. Flooding also controls such common perennials as johnsongrass, camel thorn, hoarycress, and horse nettle. In one study conducted here in California, a 13-acre area of Russian knap- weed was flooded for 60 days, killing 100% of the weed. Some weed species react differently to flooding, depending on stage of development. For example, field bindweed plants are satisfactorily controlled by flooding while bindweed seed can remain immersed for many years and will still germinate. Flooding will only control weeds which are completely immersed, thus denying oxygen to the roots and leaves. Draining is used to control aquatic weeds growing in drainage ditches and irrigation canals. Drainage is an inexpensive and effective way to control bulrush, cattail, and reed canarygrass.

The purpose of mulching is to exclude light from the weeds, therefore eliminating the photosynthetic process within the plant. The most common mulches used are hay, manure, grass clippings, straw, sawdust, wood chips, rice hulls, black paper and black plastic film. For perennial weeds the layer of hay, manure, etc. on the soil must be thicker (2-4 feet and more) than for the control of annual weeds. The most effective mulching material is the kind applied as a continuous sheet (i.e. black paper or black plastic). The particle mulches cannot prevent all the weeds from breaking through. The main crops where mulches are used are strawberries, sugar cane and pineapple. Unfortunately, mulching is quite expensive for material and application, and therefore limited to small areas or high value crops. One of the most difficult aspects of weed control has been the killing of ungerminated weed seeds in the soil. To date soil fumigants, mainly methyl bromide, have been the major technique available for killing these seeds. Recently a new non-chemical technique, referred to as soil solar- ization, was developed in Israel. Soil solarization involves placing a clear polyethylene plastic sheet over soil that is moist and well tilled. The plastic sheet needs to be kept in place for at least 4 weeks.

Soil solarization should be done during periods of high solar radiation in order to be most effective in the shortest period of time. Incoming radiation is trapped under the clear plastic by the "greenhouse effect". This increases the soil temperature. Several experiments are currently being conducted in California on using soil solarization for weed control to investigate such factors as: which species of weeds are effectively controlled; how deep in the soil profile are weed seeds killed; what soil moisture level must be present; what soil temperatures must be reached for effective weed seed control; and how long does the plastic tarp need to stay in place. The mechanisms by which soil solarization is able to lead to the death of weed seeds is not yet completely understood. Some seed death may be directly due to the high soil temperature achieved. However, it is quite likely that there are some secondary effects such as the high soil temperatures weakening the seeds, making them more vulnerable to pathogen attack.

Physical weed control is just one of many methods in containing or eliminating specific weed problems. Generally the best weed control results from the interaction of using combinations of the various methods being practiced today. (Research Representative, Rohm and Haas Company; Professor of Plant Science, California State University, Fresno.)

Cultural Weed Control

Cultural weed control topics to be discussed will include preventive, crop rotation, competition, crop culture, smother crops and plant breeding. Preventive weed control should be practiced at the national and state levels to keep weed species out of the country and state that are not currently found here. Measures to accomplish this are primarily legal ones (i.e. Federal Noxious Weed Act, etc.). However, at the local level individual farmers can practice preventive weed control to help insure that no new weed species are introduced onto their land. Such measures would include the use of crop seeds that are free of weed seeds. If preventive weed control fails, and unless successful eradication measures are implemented quickly, a weed species will become established in a given area. Most weed species possess one or more of a series of biological mechanisms that make them difficult to control once they are established in an area. These mechanisms include; production of a large number of seeds, various types of seed dormancies to delay germination, longevity of seeds in the soil, specialized structures to aid seed dissem- ination and the development of perennial parts as a means of reproduction.

Crop rotation is a major cultural weed control technique in annual and short-term perennial crops. Wherever any one crop is grown in the same field year after year the population of certain weed species tend to increase. An example would be the build-up of nightshade weeds in Cali- fornia cotton and tomato fields. Rotating these fields to other crops can allow alternate practices to help control the nightshade. Crop-weed competition is often discussed in terms of the competition that weeds give the crop. However, one effective weed control technique is to grow the crop so as to maximize the competition it gives the weeds. Items to be considered here include general crop culture, smother crops and plant breeding. Anything that can be done in the general crop culture to get a good uniform crop stand off to a fast, vigorous start and then maintain the crop stand and vigor will greatly reduce weed problems. Such items would include the use of proper seedbed preparation, planting dates, and irrigation practices. Some crops have an inherent ability to grow fast and thus out-compete many weed species. These are referred to as smother crops. Field corn and domestic sunflowers are examples. Plant breeders have helped reduce the effects of weed competition by developing crop varieties that are more vigorous. In the future plant breeders will also be asked to develop crop varieties with allelopathic chemicals to reduce weed growth or asked to develop varieties that can tolerate certain herbicides to which that crop was originally susceptible.

Chemical and Biological methods of weed control

Chemical methods

Chemical weed control refers to any technique that involves the application of a chemical (herbicide) to weeds or soil to control the germination or growth of the weed species. In economic terms, chemical control of weeds is a very large industry and there are scores of examples of chemical weed control products. Common examples of chemicals used to control weeds in forages are 2,4-DB; EPTC; bromoxynil; paraquat. Knowledge of weed seed characteristics, morphology, ontogeny, nature of competition and degree of association with crops are pre-requisite for suggesting some efficient weed control measures. It makes the users/scientists quite acquainted with the nature and spectrum of weeds existing in the crop fields and accordingly guides them to adopt certain measures. Identification and naming of a particular weed based on its genus, species or certain biological characters may not be much useful to users since weed control usually, unless specific weed problem in certain area, aims at composite weed culture and not on individual species of weeds. Therefore, some common characteristics of the species, which are clearly visible and easily understandable by users, are to be exploited for making of their classes/groups and for recommending suitable control measures.

Chemicals that are used to kill plants or weeds are called herbicides. A proper technical know-how is a pre-requisite for successful adoption of chemical method of weed control so-called herbicide technology. One has to exercise a lot of caution while using the herbicide for uniform application as well as higher herbicide efficiency. Herbicide selectivity and its dose, time and method of application are of paramount importance/consideration before applying to a crop. **There are 5 types of herbicides:**

- Broad spectrum - these work on a wide variety of weeds
- Selective - these work on a narrow range of weeds

- Contact - these destroy weed tissue at or near the point of contact (they do not spread around the weed), and require even coverage in their application
- Systemic - these move through the weed's circulation system, and can be injected into the weed
- Residual - these can be applied to the soil and destroy by root uptake. They remain active in the ground for a certain length of time, and can control germinating seedlings.

Based on application methods herbicides can be classified as under:

1. **Soil application**
2. **Soil surface application:** Herbicides are usually applied to soil surface to form a uniform herbicide layer. Applied herbicides, due to their low solubility may penetrate only few

centimetres into the soil. Weeds germinating in the top layers are killed due to incidental absorption of herbicides.eg. triazines, ureas and anilide

3. **Soil incorporation:** Some herbicides are applied to soil surface and incorporated into the soil either by tillage or irrigation for their effectiveness.eg. volatile herbicides viz., aniline and carbamate
4. **Sub surface application:** Perennial weeds Cyperus rotundus and Cynodon dactylon are controlled by injecting herbicides to the lower layers of the soil at several points.
5. **Band application:** Herbicides are applied as narrow bands over or along the crop row. Weeds in between crop rows can be controlled by intercultivation or band application of herbicide. This method is useful where labour is expensive and intercultivation is possible. eg. weeds in maize can be controlled effectively by spraying atrazine on seed row at the time of sowing.

B) Foliar application

6. **Blanket application:** Application of herbicide over the entire leaf area. Selective herbicides are applied by this method.
7. **Directed application:** Herbicide is applied directly to weeds between crop rows, avoiding the crop foliage. Care is taken to avoid spray fluid falling on the crop. eg. Late weeds in cotton can be controlled by spraying non selective herbicide by directed spray.
8. **Spot application:** Herbicides are applied or poured on small patches of weeds, leaving the relatively weed free patches untreated. It minimizes the herbicide usage per unit area.

Benefits of chemical method:

- Herbicides can be applied for weed control in crop rows and where cultivation is impossible.
- Pre-emergence provide early season weed control.

- Cultivation & manual methods of weed control may injure the root system.

- Herbicides reduce the need for pre-planting tillage. They are extremely useful in minimal / zero tillage.
- Herbicides can control many perennial weed which cannot be controlled by other methods. Eg: Cyperus,eg: Rice ecosystem

Limitation of chemical method of weed control:

- According to World Health Organization (WHO) :"Any substance or mixture of substances in food for man or animals resulting from the use of a pesticide and includes any specified derivatives, such as degradation and conversion product, metabolites, reaction products, and impurities that are considered to be of toxicological significance" are defined as herbicide/pesticide residues.

- Following herbicides registered and used in India, classified as potential carcinogens by the US EPA: Alachlor (B2), Atrazine (C), Diclofop-Methyl (C), Metolachlor (C), Oxadiazon (C), Oxyflourfen (C), Trifluralin (C).
- Herbicides banned in India: 2,4,5-T,Nitrofen, Paraquat dimethyl sulphate, Maleic hydrazide
- Herbicides still under review :Atrazine, Butachlor, Pendimethalin, Mepiquat chloride, Linuron
- Herbicide residues in soil and plant parts at harvest

- Residues in various cropping system and agroclimatic condition under AICRP-WC
- Herbicide persistence in soil (days): Atrazine (45-90), Alachlor (60-80) , 2, 4-D (45-90), Butachlor (60-100), Fluzifop p-butyl (30-90) Isoproturon (90-120), Imazosulfuron (60-90), Metoxuron (>80), Metribuzin (20-100), Pendimethalin (60-200)

- Herbicide residues and human health implications :
- Increasing incidences of acute herbicide such as butachlor, fluchloralin, paraquat, 2, 4D, pendimethalin, glyphosate etc are emerging in India.
- Paraquat poisoning is an uncommon entity in India, and is associated with a high mortality rate.

- Acute respiratory distress syndrome because of paraquat usually appears 24–48 h after ingestion .
- Most frequent routes of exposure to herbicides are, either accidentally or intentionally or through direct skin contact.
- 20 to 50 μg/mL concentrations of fluchloralin resulted in a significant dependent increase in number of micronucleated cells of human.
- butachlor in intracellular ROS production & consequent mitochondrial dysfunction, oxidative DNA damage, and chromosomal breakage, which eventually triggers necrosis in human PBMN cells
- health hazards, if not used properly, we have to find a way to deal with weeds as well as residues

- Residues in various cropping system and agroclimatic condition under AICRP-WC

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Biological method of weed control

Use of living organism's viz., insects, disease organisms, herbivorous fish, snails or even competitive plants for the control of weeds is called biological control. In biological control method, it is not possible to eradicate weeds but weed population can be reduced. This method is not useful to control all types of weeds. Introduced weeds are best targets for biological control.

Qualities of bio-agent

1. The bio-agent must feed or affect only one host and not other useful plants
2. It must be free of predators or parasites.
3. It must readily adapt to environment conditions.
4. The bio-agent must be capable of seeking out itself to the host.
5. It must be able to kill the weed or atleast prevent its reproduction in some direct or indirect way.
6. It must possess reproductive capacity sufficient to overtake the increase of its host species, without too much delay.

Merits

1) Least harm to the environment
2) No residual effect
3) Relatively cheaper and comparatively long lasting effect
4) Will not affect non-targeted plants and safer in usage

Demerits

1) Multiplication is costlier
2) Control is very slow
3) Success of control is very limited
4) Very few host specific bio-agents are available at present

Mode of action

a. Differential growth habits, competitive ability of crops and varieties prevent weed establishment Eg. Groundnut, cowpea fast growing and so good weed suppresser.
b. Insects kill the plants by exhausting plant food reserves, defoliation, boring and weakening structure of the plant.
c. Pathogenic organisms damage the host plants through enzymatic degradation of cell constituents, production of toxins, disturbance of harmone systems, obstruction in the translocation of food materials and minerals and malfunctioning of physiological processes.

Outstanding and feasible examples of biological weed control

a. Larvae of Coctoblastis cactorum, a moth borer, control prickly pear Opuntia sp. The larvae tunnel through the plants and destroy it. In India it is controlled by cochinial insects Dactylopius indicus and D. tomentosus
b. Lantana camara is controlled by larvae of Crocidosema lantana, a moth bores into the flower, stems, eat flowers and fruits.
c. Cuscuta spp. is controlled by Melanagromyza cuscutae
d. Cyperus rotundus - Bactra verutana a moth borer
e. Ludiwigia parviflora is completely denuded by Altica cynanea (steel blue beetle)
f. Herbivorous fish Tilapia controls algae. Common carp, a non-herbivorous fish controls sub-mersed aquatic weeds. It is apparently due to uprooting of plants while in search of food. Snails prefer submersed weeds.

Bio-Herbicides/ Mycoherbicides

Defination: The use of plant pathogen which are expected to kill the targeted weeds.

These are native pathogen, cultured artificially and sprayed just like post-emergence herbicides each season on target weed, particularly in crop areas. Fungal pathogens of weed have been used to a larger extent than bacterial, viral or nematode pathogens, because, bacteria and virus are unable to actively penetrate the host and require natural opening or vectors to initiate disease in plants.

Here the specific fungal spores or their fermentation product is sprayed against the target weed. Some registered mycoherbicides in western countries are tabulated below.

No	Product	Content	Target weed
1.	Devine	A liquid suspension of fungal spores of Phytophthora palmivora causes root rot.	Strangle vine (Morrenia odorata) in citrus
2.	Collego	Wettable powder containing fungal spores of Colletotrichum gloeosporoides causes stem and leaf blight	Joint vetch (Aeschyomone virginica) in rice, soybean
3.	Bipolaris	A suspension of fungal spores of Bipolaris sorghicola	Jhonson grass (Sorghum halepense)
4.	Biolophos	A microbial toxin produced as fermentation product of Steptomyces hygroscopicus	Non-specific, general vegetation

Classification of Herbicides

Herbicides:

Chemical method of weed control is very effective in certain cases and have great scope provided the herbicides are cheap, efficient and easily available. The chemicals used for killing the weeds or inhibiting growth of weeds are called herbicides (Weedicides).

Classification of Herbicides:

Herbicides are classified in different ways:

A) **First Group Chemical Herbicides:**

I) Classification of herbicides according to chemical composition.

II) Classification of herbicides according to their use.

III) Classification of herbicides based on time of application.

IV) Classification of herbicides according to Formulation.

V) Classification of herbicides according to residual effect.

B) **Second Group – Bio herbicides**

C) Third Group herbicidal mixtures.

Classification of herbicide

I) Classification of Herbicide Based on Chemical Nature or Composition

Compounds having chemical affinities are grouped together. This is useful in liting and characterizing herbicides.

i) Inorganic Herbicides: Contain no carbon actions in their molecules. These were the first chemicals used for weed control before the introduction of the organic compounds, example are:

a) Acids: Arsenic acid, arsenious acid, arsenic trioxide sulphuric acid.

b) Salts: Borax, copper sulphate, ammonium sulphate, Na chlorate , Na arsenite , copper nitrate.

ii) Organic Herbicides: Oils and non oils contain carbon and hydrogen in their molecules.

a) Oils: Diesel oil, standard solvent, xylene-type, aromatic oils, polycyclic , aromatic oils etc.

b) Aliphatic: Dalapon, TCA, Acrolein, Glyphosphate methyl bromide.

c) Amides: Propanil, butachlor, alachlor, CDAA, Diphenamide, Naptalam, Propachlor.

d) Benzoics: 2,3,6 TBA, Diacamba, tricamba, chloramben, Fenac.

e) Bipyridyliums: Paraquat , diquat.

f) Carbamates: Propham, chloropham, barban.

g)Thocarbamates: Butylate, dilate, triallate, EPTC, molinate, pebulate, vernolate, enthlocarb, aslum, cycolate.

h) Dithiocarbamates:CDEC , Metham.

i) Nitralin (Benzonitrates):Dichlobenil , bromoxynil, ioxynil.

j) Ditroanilines (Toluidines) : Benefin, nitralin, trifluralin, butralin, dinitramine, fluchlorine, oxyzalin, penoxalin.

k) Phenoxy: 2,4-D, 2,4 , 5-T, MCPB, 2,4-DB, 2,4- DP, 2,4 , 5-TP (silvex)

l) Triazines: Atrazine, simazine, ametryne , terbuteryne, cyprazinc, Metribuzin, prometryn, propazine.

m) Ureas: Monuron, diuron, fenuron, neburon, flumeturon, mothabenzathiazuron- buturon, chlorbromuron, chloroxuron, norea siduson, metoxuron.

n) Uracils: Bromacil, terbacil, lenacil.

o) Diphenyl Ethers: Nitrogen, flurodifen.

p) Organic Arsenicals: Cacodlic acid, MSMA, DSMA.

q) Others: Bentazon, Piclaram, Pyrazon, Pyrichlor, endothall, bensulphioe, MH, DCPA.

Classification of Herbicides According to Their Use or Mode of Action (Physiological)

***I)* Selective**:

a. Foliage Application

1. Contact: DNBP, Propanil, EPTC, Nitroten,

2. Tran located: 2,4-D, 2,4,5-T, MCPB, MCPA, Silvex(2,4 ,5TP), Propanil, Monuron, MSMA

b) Soil-(Root) Application:

MCPA, TCA, Nitrofen, Dinitrophenols, Butachlor, Simazine, Atrazine

II) **Non-Selective:**

a) Foliage Application:

1. Contact: Paraquat, Sulphuric acid, Sodium arsenite, Ammate

2. Translocated: Dalapon, Acid Arsenical, Sodium chloride, Glyphosate

b) **Soil Application (Root):**

- ***Soil Fumigants:*** Cyanamide, Methyl bromide, Carbon disulphide, Trifluralin
- ***Soil Sterillont:*** TCA, Sodium Chloride, Boron, Dluron, Monuron, Atrazine, Fenac

Important Definition in Herbicides

1. Selective Herbicides: The chemicals which kills or retards the growth of some plants with little or no injury to other plants.

2. Non-Selective Herbicides: These chemicals are toxic to all the plants or kill all kinds of vegetation.

3. Contact Herbicides: A herbicides which kills only those plants or retards the growth of those plants which comes in direct contact.

4. Tran located Herbicides: The herbicides which are absorbed by the one part of the plants and exert a toxic action to other parts. These are also known as systemic herbicides. These absorbed chemicals upset the plant growth and metabolic processes.

5. Soil Fumigants: They usually function as a vapor or gas that diffuse through the soil and have relatively short life in the soil.

6. Soil Sterilants :Any chemical which prevent the growth of green plants when present in the soil is considered as soil Sterilants.

Classification of Herbicides Based on Time of Application

a) Pre-Planting/ Pre-Sowing: Trifluralin, fluchloralin

b) Per-Emergence:Simazine, Atrazine, Nitrofen, Alachlor, Butachlor

c) Post-Emergence: 2,4-D, 2,4,5-T, MCPA, MCPB, Propanil, Dalapon, Glyphosate, Silvex, Paraquat

Definition

a. Pre-Planting: These herbicides are applied before a crop is planted are called pre-planting herbicides. The herbicides is usually incorporated into the soil to reduce volatility and photo decomposition. *e. gParaquat , Basalin*.

b. Pre- Emergence Herbicides: Pre-Emergence herbicides is most effective when applied ***before the emergence of crop and weeds or the term may also refer to herbicides use after weed has emerged or established but before crop emerge*** e.g Simazine, Atrazine.

c. Post-Emergence Herbicides: Post-Emergence herbicides are most effective applied after the emergence of crop and weeds or this term may also refer to herbicides use after crop has emerged but before weeds emerge. e. g 2,4-D , Dicamba (Banvel) etc.

Classification of Herbicides on the Basis of Residual Effect

a.) Short Persistant Herbicides: Residual effect remains in the soil upto a week.e. g Paraquat, diaquat, Amitrole, DSMA, DNBP.

b.) Medium Persistant Herbicides: Residual effect remains in the soil for upto 2 to 6 weeks.

c.) Very Long Persistant Herbicides: Residual effect remains in the soil for few months even years. E. g Prometon, Fenuron, Fenac, Silvex, Boron.

Classification of Herbicides on the Basis of Formulation

i) Wettable Powder (WP): Simaine, Atraine, 2,4-D, Sodium Salt, Diuron, Linuron.

ii) Liquid Water Soluble (Concentrates) (WSC): Diaquat, Paraquat, Bromacil.

iii) Water Soluble Powder: 2,4-D, Sodium Salt, TCA.

iv) Granule: Butachlor, Bromacil, Calcium cynamide, 2,4-D ester salt, Nitrofen , Benthiocarb.

v) Dusts: 2,4-D, Ester salt.

vi) Emulsifiable Concentrates (EC): Propanil, Alachlor, Barban, Eptam.

vii) Pellet: Arsenic Compounds.

Advantages and Limitation of Herbicides or Chemical Method of Weed Control

Advantages of Herbicides or Chemical Method of Weed Control

1) The use of herbicides as pre-plant and pre-emergence treatment can control weeds, before their emergence from the soil so that crop can germinate and grow in weed free environment or with minimum competition during their tender and seedling stage. This is not possible with other methods of weed control.

2) In broadcast sown and narrow spaced crops herbicides prove very effective in reaching every weed. Mechanical methods are not so effective in such crops.

3) In wide spaced crops mechanical methods are effective for controlling weeds in rows but it is leaves the intra-row weeds. Herbicides reach to all places and control the weeds i.e inter row and intra-row weeds.

4) Weeds with similar morphological characters like crop are escaped from mechanical method. But now herbicides are available which can kill such weeds without damaging the crop.

5) Herbicides withhold the weeds for considerable period after their application. In mechanical methods weeds tend to grow back soon.

6) Deep rooted, vegetatively propagated weeds can be controlled by using translocated herbicides. The mechanical methods like weeding or hoeing are not so effective for their control. Sometimes the suitable combination of mechanical methods (deep ploughing or digging) and chemical methods is more effective for controlling such weeds.

Limitation of Herbicides (Chemical Method):

1) The use of herbicides requires technical knowhow regarding choice of particular herbicide, time of application safe dose method of application etc in the particular crop.

2) Over and under-dose of herbicides can make a market difference between the success or failure of weed control.

3) Certain herbicides because of their long residual effect limit the choice of next crop in the crop rotation.

4) Herbicides drifts may harm the neighbouring crops. E.g Ester form of 2,4,-D may harm the neighbouring crop of cotton, soybean, okra, etc.

5) Herbicides use may cause environment pollution.

Herbicide Formulations and Calculations: Active Ingredient or Acid Equivalent

The active ingredient of a pesticide formulation is the component responsible for its toxicity (phytotoxicity for herbicides) or ability to control the target pest. The active ingredient is always identified on the pesticide label, either by common name (atrazine or bentazon, for example) or chemical name (2,4-dichlorphenoxy acetic acid or diglycolamine salt of 3,6-dichlor-o-anisic acid, for example). The active ingredient statement may also include information about how the product is formulated and the amount of active ingredient contained in a gallon or pound of formulated product. For example, the Basagran label indicates the active ingredient (bentazon) is formulated as the sodium salt, and one gallon of Basagran contains 4 pounds of active ingredient.

Usually when an herbicide trade name is followed by a number and letter designation (4L, 75DF, 7EC, etc.), the number indicates how many pounds of active ingredient are in a gallon (for liquid formulations) or pound (for dry formulations) of the formulated product. The formulation designations for Basagran 4L, AAtrex 90DF, and Prowl 3.3EC indicate Basagran 4L contains 4 pounds of active ingredient (bentazon) per gallon of formulated product, AAtrex 90DF contains 0.90 pound of active ingredient (atrazine) per pound of formulated product, and Prowl 3.3EC contains 3.3 pounds of active ingredient (pendimethalin) per gallon of formulated product, respectively.

Some herbicides (atrazine, for example) have specific maximum-per-year application rates that cannot be exceeded. These maximum-per-year application rates are generally presented in terms of the total amount of active ingredient that can be applied per year. How would you calculate the pounds of active ingredient applied at a given product use rate? There are several calculations that can be used to determine the amount of active ingredient applied at a given product use rate. One of the easiest calculations is

$$\text{pounds active ingredient per acre} = \frac{\text{gallons or pounds product applied}}{\text{acre}} \times \frac{\text{pounds active ingredient}}{\text{gallons or pounds product}}$$

Using this equation, we can calculate the amount of active ingredient (bentazon) that is applied when we apply 2 pints (0.25 gallon) per acre of Basagran 4L:

$$\text{pounds of bentazon (active ingredient) applied per acre} =$$

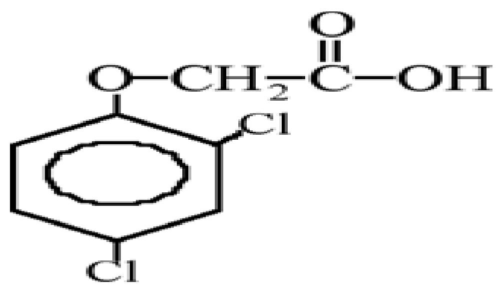
$$\frac{\text{0.25 gallons of product applied}}{\text{acre}} \times \frac{\text{4 pounds active ingredient}}{\text{gallon of product}} = \text{1 pound active ingredient per acre}$$

Sometimes, however, the numbers preceding the formulation designation (L, EC, DF, etc.) do not indicate pounds active ingredient per gallon or pound but rather the acid equivalent per gallon or pound. The term *acid equivalent* is one that many people are less familiar with. Acid equivalent may be defined as that portion of a formulation (as in the case of 2,4-D ester, for example) that theoretically could be converted back to the corresponding or parent acid. Another definition of acid equivalent is the theoretical yield of parent acid from a pesticide active ingredient that has been formulated as a derivative (esters, salts, and amines are examples of derivatives). For instance, the acid equivalent of the isooctyl ester of 2,4-D is 66 percent of the ester formulation but 88 percent of the ethyl acetate ester formulation. Why would an herbicide (one that has the acid as the parent molecule) be formulated as a derivative (ester, salt, amine, etc.) of the parent acid?

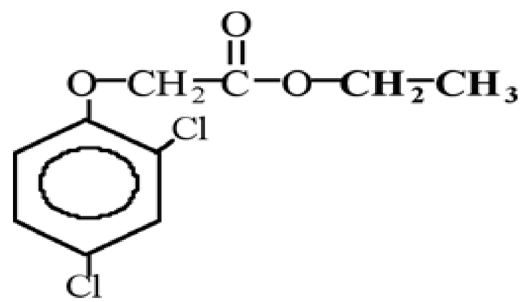
An herbicide molecule may sometimes be altered to impart some property other than herbicidal activity. *Herbicidal activity* refers to the ability of a particular herbicide to effectively bind to a target site within the plant and exert some type of lethal effect (i.e., you apply the herbicide to the plant and the plant eventually dies). Such alterations are possible with herbicide molecules that are acids (for example, molecules that have a carboxyl group as part of their structure). The acidic carboxyl hydrogen is replaced by the desired ions to form a salt or reacted with an alcohol to form an ester. Why would this be done? For example, due to the chemical characteristics of a particular herbicide molecule, the parent acid may not be readily absorbed into a plant, because it's not able to effectively penetrate the waxy cuticle covering the leaf. Somehow altering the parent acid may increase the ability of the herbicide to penetrate through the leaf much more effectively. For some postemergence herbicides, formulating the parent acid as an ester or salt is frequently done to facilitate absorption through the leaf. Other formulations or derivatives of the parent acid may increase the water solubility of the herbicide. 2,4-D (2,4-dichlorphenoxy acetic acid) is commonly formulated as an ester or amine. The ester formulation increases the lipid solubility of the herbicide, which allows it to more easily penetrate the waxy cuticle of the plant leaf. The amine formulation greatly increases the water solubility of the herbicide, which may be desirable if the product needs to be moved into the soil solution for root uptake (brush control, for example).

If an herbicide is formulated as a derivative of the parent acid, it is important to remember that the parent acid is the herbicidally active portion of the formulation. The parent acid is what binds to the herbicide target site within the plant and causes plant death. The salt or ester portion of the formulated product may allow for greater absorption into the plant but plays no role in binding to the herbicide target site. For example, when an ester herbicide penetrates the cuticle, enzymes convert the ester back to the parent acid, so following absorption, the ester part of the formulation plays no role in herbicidal activity. Modification of the parent acid (formulation as a salt, ester, or amine) may increase the amount of active ingredient in a formulation, because the amount of active ingredient listed on a product label includes both the weight of the parent acid and the weight of the salt or ester. Modification does not always, however, increase the amount of acid (herbicidally active portion) in the formulation. The acid equivalent represents the original acid portion of the molecule and is used for "apples-to-apples" comparisons of different formulations containing the same acid. Another example will hopefully alleviate some the confusion.

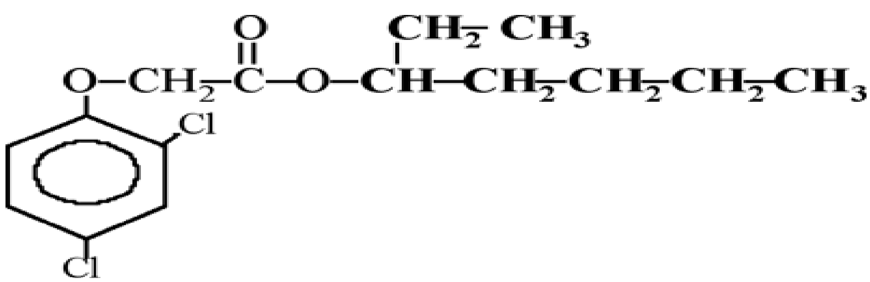
2,4-D can be formulated as various esters. The chain length of the ester can be varied but is most commonly eight carbon atoms long (isooctyl ester). Let's assume we have two ester formulations of 2,4-D: the first has only two carbon atoms forming the ester, and the second has eight carbons forming the ester. The parent acid is the same in these two formulations; the only difference is the length of the ester. These can be visualized in the following diagrams.



2,4-D acid



2,4-D ethyl acetate ester



2,4-D isooctyl ester

The structure on the left is the parent acid of 2,4-D. The second diagram is the parent acid, formulated with a 2-carbon side chain (the two added carbons are in bold text), and the third diagram is the parent acid, formulated with an 8-carbon side chain (again, the added carbon atoms are in bold text). While these added carbon atoms may modify some aspect of herbicide performance (the isooctyl ester is the most commonly used ester formulation of 2,4-D), it is the *parent acid (the one depicted in the left diagram) that acts at the target site within the plant*. The added carbon atoms of the esters add weight to the formulation and may increase the amount of active ingredient of a formulation, but they *do not* increase the amount of parent acid in the formulation. If these two formulations were commercially available, and someone wanted to know how much of the parent acid each formulation contained, the calculation to use would be based on the acid equivalent of the formulations, not the active ingredient of the formulations.

Let's assume that both the 2,4-D 2-carbon ester formulation and the 8-carbon ester formulation were commercially available and each contains 4 pounds of *active ingredient* per gallon. The application rate on the label is 1 pint per acre of either formulation. Since the application rates and the pounds of *active ingredient* per gallon are identical for each formulation, the amount of *active ingredient* applied would be the same for each formulation. If you doubt this, plug in the appropriate numbers for each formulation in the formula given previously for calculating the amount of *active ingredient* applied. Even though the amount of *active ingredient* applied is the same for each formulation, the amount of *acid* applied is *not* the same. Remember that it is the *parent acid* that binds to the target site to control the weed; the ester portion of the formulation is not involved in binding to the target site. How would we calculate the amount of acid applied?

The first step is to determine the amount of acid equivalent contained in a gallon of formulated product. Some labels indicate both the amount of active ingredient and acid equivalent contained in the formulation, while others list only active ingredient. If the pounds acid equivalent is specified on the product label, all you need to do to determine the pounds acid equivalent applied per acre is substitute pounds acid equivalent for pounds active ingredient in the equation presented previously for calculating the pounds active ingredient applied. For this example, however, let's assume that neither of these 2,4-D ester formulation labels indicates the amount of acid equivalent.

The formula that can be used to calculate the amount of acid equivalent contained in a gallon of formulated product is

$$\text{Acid equivalent} = \frac{\text{molecular weight of the acid - 1}}{\text{molecular weight of the salt or ester}} \times 100$$

We now need to provide some molecular weights (i.e., how much the molecule weighs) to complete these calculations. The molecular weight of the parent 2,4-D acid is 221.04. The molecular weight of the 2-carbon ester formulation is 29.02 (weight of the two carbons and five hydrogens) + 221.04 (weight of the parent acid) = 250.06. The molecular weight of the 8-carbon ester formulation is 333.25.

The acid equivalent of the *2-carbon* ester formulation is

$$\text{Acid equivalent} = \frac{221.04 - 1}{250.06} \times 100 = 88\%$$

So the amount of *acid equivalent* in 1 gallon of formulated product is

$$88\% \text{ acid equivalent} \times \frac{\text{4 pounds active ingredient}}{\text{gallon}} = \text{3.52 pounds active ingredient}$$

The acid equivalent of the *8-carbon* ester formulation is

$$\text{Acid equivalent} = \frac{221.04 - 1}{333.25} \times 100 = 66\%$$

So the amount of *acid equivalent* in 1 gallon of formulated product is

$$66\%\ \text{acid equivalent} \times \frac{\text{4 pounds active ingredient}}{\text{gallon}} = \text{2.64 pounds active ingredient}$$

Again we applied 1 pint (0.125 gallon) per acre of each formulation, and because they both contain 4 pounds active ingredient per gallon, the amount of *active ingredient* applied is equal. The amount of *acid* applied (that part of the formulation that actually controls the weed) for each formulation is not equal.

The amount of *acid* applied per acre with the *2-carbon* ester formulation is

$$\frac{\text{0.125 gallon of product applied}}{\text{acre}} \times \frac{\text{3.52 pounds per acre}}{\text{gallon of product}} = \text{0.44 pounds applied per acre}$$

The amount of *acid* applied per acre with the 8-carbon formulation is

$$\frac{\text{0.125 gallons of product applied}}{\text{acre}} \times \frac{\text{2.64 pounds per acre}}{\text{gallon of product}} = \text{0.33 pounds applied per acre}$$

This example demonstrates that there was more acid applied with the 2-carbon ester formulation than with the 8-carbon formulation. In practical terms, more of the part of the formulation that actually controls the weeds was applied with the 2-carbon ester formulation. To compare the herbicidally active portion of two ester, salt, or amine formulations, product equivalents should be based on the acid equivalent of a salt or ester formulation.

This exercise was done to illustrate that, to calculate equivalent rates of salt or ester formulations, the acid equivalent calculation should be used. If there is only one formulation of a salt or ester product commercially available, it wouldn't really matter if you calculated active ingredient or acid equivalent. For example, Pursuit is formulated as the ammonium salt of imazethapyr, but currently only one manufacturer markets Pursuit. There are, however, several commercial formulations of 2,4-D and glyphosate. there are over 30 different commercial formulations of glyphosate available today, and more will likely be available in the future. Not all these formulations contain the same amount of acid equivalent, so if you want to determine equivalent rates of two glyphosate-containing formulations with respect to how many molecules of glyphosate are applied, you must calculate these rates based on acid equivalent. Some calculations of acid equivalents, based on an application rate of 1 pound active ingredient per acre. This table illustrates that, when calculations are based on equivalent active ingredient, the amount of acid applied may not always be equal. It is the acid portion of a salt formulation that binds at the target site.

Typically, pure herbicide molecules are of limited value to the end user.To give them practical value and usable, most herbicides are combined with appropriate solvents or surfactants to form a product called a *formulation.* Herbicides are available as formulations and rarely as the pure chemical. In addition, a given chemical may be formulated in a variety of differing formulations and sold under different trade names.

The primary reason for formulating a herbicide is to allow the user to dispense it in a convenient carrier, such as water. The primary purpose of the carrier is to enable the uniform distribution of a relatively small amount of herbicide over a comparatively large area. In addition to providing the consumer with a form of herbicide that is easy to handle, formulating a herbicide can enhance the phytotoxicity of the herbicide, improve the shelf-life (storage) of the herbicide, and protect the herbicide from adverse environmental conditions while in storage or transit.

Formulations vary according to the solubility of the herbicide active ingredient in water, oil and organic solvents, and the manner the formulation is applied (i.e., dispersed in a carrier such as water or applied as a dry formulation itself).

Solution (S)

Solution formulations are designed for those active ingredients that dissolve readily in water. The formulation is a liquid and consists of the active ingredient and additives. When herbicides formulated as solutions are mixed with water, the active ingredient will not settle out of solution or separate.

Soluble Powder (SP)

Soluble powder formulations are similar to Solutions (S) in that, when mixed with water, these dry formulations dissolve readily and form a true solution. The formulation is dry and consists of the active ingredient and additives. When thoroughly mixed, no further agitation is necessary to keep the active ingredient dissolved in solution. Few formulations of this type are available because few active ingredients are highly soluble in water.

Emulsifiable Concentrate (E or EC)

Formulations of this type are liquids that contain the active ingredient, one or more solvents, and an emulsifier that allows mixing with water.

Formulations of this type are highly concentrated and relatively inexpensive per pound of active ingredient; easy to handle, transport, and store; require little agitation (will not settle out or separate); and are not abrasive to machinery or spraying equipment. Formulations of this type may, however, have potentially greater phytotoxicity than other formulations; exhibit a potential for over- or underdosing through mixing or calibration errors; are more easily absorbed through skin of humans or animals; and contain solvents that may cause deterioration of rubber or plastic hoses and pump parts.

Wettable Powder (W or WP)

Wettable powders are dry, finely ground formulations in which the active ingredient is combined with a finely ground carrier (usually mineral clay) along with other ingredients, to enhance the ability of the active ingredient plus carrier to suspend in water. The powder is mixed with water for application.

Wettable powders are one of the most widely used herbicide formulations and offer low cost and ease of storage, transport, and handling; lower phytotoxicity potential than ECs and other liquid formulations; and less skin and eye absorption hazard than ECs and other liquid formulations.

Some disadvantages are that they require constant and thorough agitation in the spray tank, are abrasive to pumps and nozzles (causing premature wear), may produce visible residues on plant and soil surfaces, and can create an inhalation hazard to the applicator while handling (pouring and mixing) the concentrated powder.

Liquid Flowable (F or FL)

Liquid flowable formulations consist of finely ground active ingredient suspended in a liquid. Flowables are mixed with water for application, are easily handled and applied, and seldom clog nozzles. Some of their disadvantages are that they may leave a visible residue on plant and soil surfaces, and typically require constant and thorough agitation to remain in suspension.

Dry Flowables and Water-Dispersible Granules (DF, DG or WDG)

Dry flowable and water-dispersible granule formulations are much like wettable powders except that the active ingredient is formulated on a large particle (granule) instead of onto a ground powder. This type of formulation offers essentially the same advantages and disadvantages as wettable powder formulations. However, these formulations generally are more easily mixed and measured than wettable powders. Because they create less dust when handling, they cause less inhalation hazard to the applicator during pouring and mixing.

Granules and Pellets (G, P or PS)

Used exclusively for soil applied herbicides, the active ingredient is formulated onto large particles (granules or pellets). The primary advantages of this type of formulation are that the formulation is ready to use with simple application equipment (seeders or spreaders), and the drift potential is low because the particles are large and settle quickly. The disadvantages of these formulations are that they do not adhere to foliage (not intended for foliar applications), and may require mixing into the soil in order to achieve adequate herbicidal activity.

How and Why Should You Select a Specific Formulation Type?

The active ingredient is the agent in a formulation that has a specific effect on a pest (weed). Select the formulation that will be best for an application and consider the following points:

What is the pest you are concerned with?

- How will the formulation affect the phytotoxicity of the undesirable plant(s) you wish to manage and/or the desirable plant(s) you wish to maintain?
- How will the formulation influence the compatibility of other crop protection chemicals?

What application machinery is available to you and most suited for the job

- How will the formulation affect the life of your application equipment?
- Is your equipment designed for applying a particular formulation? What concerns do you have with safety for the applicator and other people?

An active ingredient may be available in a variety of formulations. These formulations may vary in ease of handling and human exposure potential

Some of the specific issues to consider when selecting an herbicide formulation are described above. The table which follows illustrates the general features associated with a specific herbicide formulation, and can be used as an aid in selecting an herbicide based on differences in formulation

Some of the information for this publication was adapted from the following sources: *Applying Pesticides Correctly*, Slide Set - Unit 6 (Harmful Effects), Slide Set - Unit 7 (Personal Protective Equipment), Slide Set - Unit 8 (Pesticide Handling Decisions), The Ohio State University, USDA, office of pesticide Programs, US EPA.

Table 1: A comparison of herbicide formulation handling, application, and performance characteristics.

Formulations	**Mixing/Loading Hazards**	**Phytotoxicity**	**Effect on Application Equipment**	**Agitation Required**	**Method of Application**	**Compatible With Other Formulations**
wettable powders	dust inhalation	safe	abrasive	yes	foliar and soil	highly
dry flowables/ water-dispersible powders	safe	safe	abrasive	yes	foliar and soil	good
soluble powders	dust inhalation	usually safe	non-abrasive	no	foliar and soil	fair
emulsifiable	spills and	possible	may affect			

concentrates	splashes		rubber parts	yes	foliar and soil	fair
liquid flowables	spills and splashes	possible	may affect rubber parts	yes	foliar and soil	fair
solutions	spills and splashes	safe	non-abrasive	no	foliar and soil	fair
granules and pellets	safe	safe	-	no	soil	-

HERBICIDE BRAND NAMES, ACTIVE INGREDIENTS, CHEMICAL FAMILIES, AND MODES OF ACTION

Brand Names	**Active Ingredient(s)**	**Chemical Family**	**Mode of Action[1]**
AAtrex	atrazine	Triazine	5
Accent	nicosulfuron	Sulfonylurea	2
Acclaim Extra	fenoxaprop	Aryloxyphenoxy-propionate	1
Acumen	pendimethalin	Dinitroaniline	3
Aim	carfentrazone	Triazolinone	14
Alachlor	alachlor	Chloroacetamide	15
Alanap	naptalam	Phthalamate simicarbazone	19
Arrow	clethodim	Cyclohexanedione	1
Arsenal	imazapyr	Imidazolinone	2
Atrazine	atrazine	Triazine	5
Assure II	quizalofop	Aryloxyphenoxy-propionate	1
Axial	pinoxaden	phenylpyrazoline	1
Axiom	flufenacet + metribuzin	Oxyacetamide + triazinone	15 + 5
Authority First	sulfentrazone + cloransulam	Triazolinone + triazolopyrimidine	14 + 2
Authority MTZ	Sulfentrazone + metribuzin	Triazolinone + triazinone	14 + 5
Backdraft	glyphosate + imazaquin	Glycine + imidazolinone	9 + 2
Balan	benefin	Dinitroaniline	3
Balance Flexx	isoxaflutole	isoxazole	28

Banvel	dicamba	Benzoic acid	4
Banvel-K + Atrazine	dicamba + atrazine	Benzoic acid + triazine	4 + 5
Barricade	prodiamine	Dinitroaniline	3
Basagran	bentazon	Benzothiadiazinone	6
Basis	rimsulfuron + thifensulfuron	Sulfonylurea	2 + 2
Basis Gold	rimsulfuron + thifensulfuron + atrazine	Sulfonylurea + sulfonylurea + triazine	2 + 2 + 5
Beacon	primisulfuron	Sulfonylurea	2
Bensumec	bensulide	Unclassified	17
Beyond	imazamox	Imidazolinone	2
Bicep II Magnum	atrazine + s-metolachlor	Triazine + chloroacetamide	5 + 15
Blade	metsulfuron	Sulfonylurea	2
Boundary	s-metolachlor + metribuzin	Chloroacetamide + triazine	15 + 5
Brawl, Brawl II	s-metolachlor	Chloroacetamide	15
Brawl II ATZ	s-metolachlor + atrazine	Chloroacetamide + triazine	15 + 5
Breakfree	acetochlor	Chloroacetamide	15
Breakfree ATZ	acetochlor + atrazine	Chloroacetamide + triazine	15 + 5

HERBICIDE BRAND NAMES, ACTIVE INGREDIENTS, CHEMICAL FAMILIES, AND MODES OF ACTION (continued)

Brand Names	Active Ingredient(s)	Chemical Family	Mode of Action[1]
Break-Up	pronamide	Benzamide	3
Buctril	bromoxynil	Nitrile	6
Bullet	alachlor + atrazine	Chloroacetamide + triazine	15 + 5
Butoxone	2,4-DB	Phenoxy-carboxylic acid	4
Butyrac	2,4-DB	Phenoxy-carboxylic acid	4
Cadet	Fluthiacet-methyl	thiadiazole	14
Cadre	imazapic	Imidazolinone	2
Callisto	mesotrione	Triketone	27
Camix	s-metolachlor + mesiotrione	Chloroacetamide + triketone	15 + 27
Canopy	metribuzin + chlorimuron	Triazinone + sulfonylurea	5 + 2
Canopy EX	chlorimuron + tribenuron	Sulfonylurea + sulfonylurea	2 + 2
Canopy XL	sulfentrazone + chlorimuron	Diphenylether + sulfonylurea	14 + 2
Caparol	prometryn	Triazine	5
Capreno	Thiencarbazone + tembotrione	Triazolone + triketone	2 + 27
Celebrity, Celebrity Plus	nicosulfuron + dicamba	Sulfonylurea + benzoic acid	2 + 4
Celsius	Iodosulfuron + thiencarbzone + dicamba	Sulfonylurea + triazolone + benzoic acid	2 + 2 + 4
Certainty	Sulfosulfuron	Sulfonylurea	2
Charger Basic, Charger MAX	s-metolachlor	Chloroacetamide	15
Charger MAX ATZ	atrazine + s-metolachlor	Triazine + chloroacetamide	5 + 15
Chateau	flumioxazin	N-phenylphthalimide	14
Cimarron Max	metsulfuron + 2,4-D + dicamba	Sulfonylurea + phenoxy-carboxylic acid + benzoic acid	2 + 4 + 4
Cimarron Plus	metsulfuron + chlorsulfuron	Sulfonylurea	2 + 2

Cinch	s-metolachlor	Chloroacetamide	15
Cinch ATZ	s-metolachlor + atrazine	Chloroacetamide + triazine	15 + 5
Clarity	dicamba	Benzoic acid	4
Classic	chlorimuron	Sulfonylurea	2
Clethodim	clethodim	Cyclohexanedione	1
Clopyr AG	clopyralid	Pyridine carboxylic acid	4
Cobra	lactofen	Diphenylether	14
Command	clomazone	Isoxazolidinone	13
Confidence	acetochlor	Chloroacetamide	15
Confidence Xtra	acetochlor + atrazine	Chloroacetamide + triazine	15 + 5
Confront	Clopyralid + triclopyr	Pyridine carboxylic acid + pyridine carboxylic acid	4 + 4
Corsair	sulfometuron	Sulfonylurea	2
Cotoran	fluometuron	Urea	7

HERBICIDE BRAND NAMES, ACTIVE INGREDIENTS, CHEMICAL FAMILIES, AND MODES OF ACTION (continued)

Brand Names	Active Ingredient(s)	Chemical Family	Mode of Action[1]
Corvus	thiencarbazone + isoxaflutole	Triazolone + isoxazole	2 + 27
Crossbow	2,4-D + triclopyr	Phenoxy-carboxylic acid + pyridine carboxylic acid	4 + 4
Curbit	ethalfluralin	Dinitroaniline	3
Dacthal	DCPA	Benzoic acid	3
Define	flufenacet	Oxyacetamide	15
Degree	acetochlor	Chloroacetamide	15
Degree Xtra	acetochlor + atrazine	Chloroacetamide + triazine	15 + 5
Devrinol	napropamide	Acetamide	15
Diablo	dicamba	Benzoic acid	4
Dicamba	dicamba	Benzoic acid	4
Dimension	dithiopyr	Pyridine	3
Direx	diuron	Urea	7
Dismiss	sulfentrazone	Triazolinone	14
Distinct	dicamba + diflufenzopyr	Benzoic acid + semicarbazone	4 + 19

Diuron	diuron	Urea	7
Double Team	acetochlor + atrazine	Chloroacetamide + triazine	15 + 5
Drive, Drive XLR8	quinclorac	Quinaline carboxcylic acid	4 - dicots
DSMA, numerous brands	DSMA	Organoarsenical	17
Dual II, Dual II Magnum	s-metolachlor	Chloroacetamide	15
Echelon	Prodiamine + sulfentrazone	Dinitroaniline + Triazolinone	3 + 14
Envoke	trifloxysulfuron	Sulfonylurea	2
Envoy	clethodim	Cyclohexanedione	1
Eptam	EPTC	Thiocarbamate	8
Equip	foramsulfuron + iodosulfuron	Sulfonylurea	2 + 2
Eradicane	EPTC	Thiocarbamate	8
Escalade	2,4-D + dicamba + fluroxypyr	Phenoxy + benzoic acid + pryridine carboxylic acid	4 + 4 + 4
Establish	dimethenamid-p	Chloroacetamide	15
Establish ATZ	dimethenamid-p + atrazine	Chloroacetamide + triazine	15 + 5
ET	pyraflufen ethyl	Phenylpyrazole	14
Evik	ametryne	Triazine	5
Exceed	primisulfuron + prosulfuron	Sulfonylurea + Sulfonylurea	2 + 2
Expert	glyphosate + s-metolachlor + atrazine	Glycine + chloroacetamide + triazine	9 + 15 + 5
Express	tribenuron	Sulfonylurea	2
Extreme	glyphosate + imazethapyr	Glycine + imidazolinone	9 + 2
Finesse	chlorsulfuron + metsulfuron	Sulfonylurea + sulfonylurea	2 + 2
Firestorm	paraquat	Bipyridylium	22

Herbicide **brand names, active ingredients, chemical families,and modes of action**

Brand Names	**Active Ingredient(s)**	**Chemical Family**	**Mode of Action[1]**
Firstrate	cloransulam	Triazolopyrimidine	2
Firstshot	Tribenuron + thifensulfuron	Sulfonylurea + Sulfonylurea	2 + 2
Flexstar	Fomesafen	Diphenylether	14
Flexstar GT	Fomesafen + glyphosate	Diphenylether + glycine	14 + 9
Fluometuron	fluometuron	Urea	7
ForeFront	aminopyralid + 2,4-D	pyridinecarboxylic acid + phenoxy-carboxylic acid	4 + 4
Freehand	Dimethenamid + pendimethalin	Chloracetamide + dinitroaniline	15 + 3
FulTime	acetochlor	Chloroacetamide	15
Fusilade DX, II	fluazifop	Aryloxyphenoxy-propionate	1
Fusion	fluazifop + fenoxaprop	Aryloxyphenoxy-propionate + aryloxyphenoxy- propionate	1 + 1
Gallery	isoxaben	Benzamide	21
Galligan	oxyfluorfen	Diphenylether	14
Gangster	flumioxazin + cloransulam	N-phenylphthalimide + triazolopyrimidine	14 + 2
Garlon	triclopyr	pyridinecarboxylic acid	4
Glyphosate (numerous brands)	glyphosate	Glycine	9
Goal/GoalTender	oxyfluorfen	Diphenylether	14
Gramoxone	paraquat	Bipyridylium	22
Grazon P+D	2,4-D + picloram	Phenoxy-carboxylic acid + pyridinecarboxylic acid	4 + 4
Guardsman Max	dimethenamid-p + atrazine	Chloroacetamide + triazine	15 + 5
Gunslinger	2,4-D + picloram	Phenoxy-carboxylic acid + pyridinecarboxylic acid	4 + 4
Halex GT	mesiotrione + s-metolachlor + glyphosate	Triketone + chloroacetamide + glycine	27 + 15 + 9
Harmony Extra	thifensulfuron + tribenuron	Sulfonylurea + sulfonylurea	2 + 2

Harmony GT	thifensulfuron	Sulfonylurea	2
Harness	acetochlor	Chloroacetamide	15
Harness Xtra	acetochlor + atrazine	Chloroacetamide + triazine	15 + 5
Hoelon	diclofop	Aryloxyphenoxy-propionate	1
Huskie	Bromoxynil + pyrasulfotole	Nitrile + benzoylpyrazole	6 + 27
Hyvar	bromacil	uracil	5
Ignite, Ignite 280	glufosinate	Phosphinic acid	10
Illoxan	diclofop	Aryloxyphenoxy-propionate	1
Impact	topramezone	benzoylpyrazole	27
Image	imazaquin	Imidazolinone	2
Impose	imazapic	Imidazolinone	2
Intrro	alachlor	Chloroacetamide	15
Karmex	diuron	Urea	7
Kerb	pronamide	Benzamide	3

HERBICIDE BRAND NAMES, ACTIVE INGREDIENTS, CHEMICAL FAMILIES, AND MODES OF ACTION (continued)

Brand Names	Active Ingredient(s)	Chemical Family	Mode of Action[1]
Keystone	acetochlor + atrazine	Chloroacetamide + triazine	15 + 5
Lariat	alachlor + atrazine	Chloroacetamide + triazine	15 + 5
Laudis	tembotrione	Triketone	27
Layby Pro	diuron + linuron	Urea + urea	7 + 7
Lexar	mesotrione + s-metolachlor + atrazine	Triketone + chloroacetamide + triazine	27 + 15 + 5
Liberty	glufosinate	Phosphinic acid	10
Liberty ATZ	glufosinate + atrazine	Phosphinic acid + triazine	10 + 5
Lightning	imazethapyr + imazapyr	Imidazolinone + imidazolinone	2 + 2
Linex	linuron	Urea	7
Lontrel	Clopyralid	pyridinecarboxylic acid	4
Lorox	linuron	Urea	7
Lumax	mesotrione + s-metolachlor +	Triketone + chloroacetamide + atrazine	27 + 15 + 5

	atrazine		
Manor	metsulfuron	Sulfonylurea	2
Marksman	dicamba + atrazine	Benzoic acid + triazine	4 + 5
Matrix	rimsulfuron	Sulfonylurea	2
Maverick	sulfosulfuron	Sulfonylurea	2
Medal, Medal II	s-metolachlor	Chloroacetamide	15
Me-Too-Lachlor, Me-Too-Lachlor II	metolachlor	Chloroacetamide	15
Metri	metribuzin	Triazinone	5
Metribuzin	metribuzin	Triazinone	5
Micro-Tech	alachlor	Chloroacetamide	15
Milestone	aminopyralid	pyridinecarboxylic acid	4
Monument	trifloxysulfuron	Sulfonylurea	2
Moxy	bromoxynil	Nitrile	6
MSMA (numerous brands)	MSMA	Organoarsenical	17
One-Time	Dicamba + MCPP + quinclorac	Benzoic acid + phenoxy + quinaline carboxylic acid	4 + 4 + 4
Option	foramsulfuron	Sulfonylurea	2
Osprey	mesosulfuron	Sulfonylurea	2
Oust	sulfometuron	Sulfonylurea	2
Outlaw	2,4-D + dicamba	Phenoxy-carboxylic acid + benzoic acid	4 + 4
Outlook	dimethenamid-p	Chloroacetamide	15
OxiFlo	oxyfluorfen	Diphenylether	14
Parallel, Parallel PCS	metolachlor	Chloroacetamide	15
Panoramic	imazapic	Imidazolinone	2
Parazone	paraquat	Bipyridylium	22

HERBICIDE BRAND NAMES, ACTIVE INGREDIENTS, CHEMICAL FAMILIES, AND MODES OF ACTION (continued)

Brand Names	Active Ingredient(s)	Chemical Family	Mode of Action[1]
Parrlay	metolachlor	Chloroacetamide	15
PastureGard	Triclopyr + fluroxypyr	pyridinecarboxylic acid	4 + 4
Peak	prosulfuron	Sulfonylurea	2
Pendant	pendimethalin	Dinitroaniline	3
Pendimax	pendimethalin	Dinitroaniline	3
Pendulum	pendimethalin	Dinitroaniline	3
Pennant	s-metolachlor	Chloroacetamide	15
Permit	halosulfuron	Sulfonylurea	2
Phoenix	lactofen	Diphenylether	14
Plateau	imazapic	Imidazolinone	2
Poast, Poast Plus	sethoxydim	Cyclohexanedione	1
Prefar	bensulide	Phosphorodithioate	8
Prefix	s-metolachlor + fomesafen	Chloracetamide + diphenylether	15 + 14
Princep	simazine	Triazine	5
Priority	carfentrazone + halosulfuron	Triazolinone + sulfonylurea	14 + 2
Prograss	ethofumesate	Benzofuran	16
Prometryn	prometryn	Triazine	5
Prowl, Prowl H2O	pendimethalin	Dinitroaniline	3
Pursuit	imazethapyr	Imidazolinone	2
Python	flumetsulam	Triazolopyrimidine	2
Q4	2,4-D + dicamba + quinclorac + sulfentrazone	Phenoxy + benzoic acid + quinaline carboxylic acid + triazolinone	4 + 4 + 4 + 14
Quincept	2,4-D + dicamba + quinclorac	Phenoxy + benzoic acid + quinaline carboxylic acid	4 + 4 + 4

QuickSilver	carfentrazone	Triazolinone	14
Raptor	imazamox	Imidazolinone	2
Reflex	fomesafen	Diphenylether	14
Remedy	triclopyr	pyridinecarboxylic acid	4
Resolve	rimsulfuron	Sulfonylurea	2
Resource	flumiclorac-pentyl	N-phenylphthalimide	14
Revolver	foramsulfuron	Sulfonylurea	2
Reward	diquat	Bipyridylium	22
Ro-Neet	cycloate	Thiocarbamate	8
Ronstar	oxadiazon	Oxadiazole	14
Sandea	halosulfuron	Sulfonylurea	2
Scepter	imazaquin	Imidazolinone	2
Sedgehammer	halosulfuron	Sulfonylurea	2
Select/Select Max	clethodim	Cyclohexanedione	1
Sethoxydim G- and E-Pro	sethoxydim	Cyclohexanedione	1

HERBICIDE BRAND NAMES, ACTIVE INGREDIENTS, CHEMICAL FAMILIES, AND MODES OF ACTION (continued)

Brand Names	Active Ingredient(s)	Chemical Family	Mode of Action[1]
Sencor	metribuzin	Triazinone	5
Sequence	glyphosate + s-metolachlor	Glycine + chloroacetamide	9 + 15
Sharpen	saflufenacil	pyrimidinedione	14
Simazine	simazine	Triazine	5
Sim-Trol	simazine	Triazine	5
Sinbar	terbacil	Uracil	5
Sonalan	ethalfluralin	Dinitroaniline	3
Sonic	sulfentrazone + cloransulam	Triazolinone + triazolopyrimidine	14 + 2

Solicam	norflurazone	Pyridazinone	12
Spartan	sulfentrazone	Triazolinone	14
Spike	tebuthiuron	Urea	7
Spin-Aid	phenmedipham	Phenylcarbamate	5
Spotlight	fluroxypyr	pyridinecarboxylic acid	4
Squadron	imazaquin + pendimethalin	Imidazolinone + dinitroaniline	2 + 3
Stalwart, Stalwart C	metolachlor	Chloroacetamide	15
Stalwart Xtra	metolachlor + atrazine	Chloroacetamide + triazine	15 + 5
Staple	pyrithiobac	Pyrimidinyl(thio)benzoate	2
Starfighter	ozadiazon	oxadiazole	14
Status	dicamba + diflufenzopyr	Benzoic acid + semicarbazone	4 + 19
Steadfast	nicosulfuron + rimsulfuron	Sulfonylurea + sulfonylurea	2 + 2
Steadfast ATZ	nicosulfuron + rimsulfuron + atrazine	Sulfonylurea + sulfonylurea + triazine	2 + 2 + 5
Stealth	pendimethalin	Dinitroaniline	3
Sterling	dicamba	Benzoic acid	4
Stinger	clopyralid	Pyridine carboxylic acid	4
Storm	acifluorfen + bentazon	Diphenylether + benzothiadiazinone	14 + 6
Stout	nicosulfuron + thifensulfuron	Sulfonylurea + sulfonylurea	2 + 2
Strategy	ethalfluralin + clomazone	Dinitroaniline + isoxazolidinone	3 + 13
Strongarm	diclosulam	Triazolopyrimidine	2
Suprend	prometryn + trifloxysulfuron	Triazine + sulfonylurea	5 + 2
Surflan	oryzalin	Dinitroaniline	3
Surge	2,4-D + dicamba + MCPP + sulfentrazone	Phenoxy + benzoic acid + phenoxy + triazolinone	4 + 4 + 4 = 14
Surmount	picloram + fluroxypyr	pyridinecarboxylic acid	4

Sutan+	Butylate	Thiocarbamate	8
Surpass	acetochlor	Chloroacetamide	15
Synchrony XP	chlorimuron + thifensulfuron	Sulfonylurea + sulfonylurea	2 + 2

HERBICIDE BRAND NAMES, ACTIVE INGREDIENTS, CHEMICAL FAMILIES, AND MODES OF ACTION (continued)

Brand Names	**Active Ingredient(s)**	**Chemical Family**	**Mode of Action[1]**
Targa	quizalofop	Aryloxyphenoxy-propionate	1
Tenacity	mesotrione	triketone	27
TopNotch	acetochlor	Chloroacetamide	15
Tower	dimethenamid	chloracetamide	15
Transline	clopyralid	pyridinecarboxylic acid	4
TranXit	rimsulfuron	Sulfonylurea	2
Treflan	trifluralin	Dinitroaniline	3
Triangle	atrazine + metolachlor	Triazine + chloroacetamide	5 + 15
Trifluralin	trifluralin	Dinitroaniline	3
Trigger	clethodim	Cyclohexanedione	1
Trilin	trifluralin	Dinitroaniline	3
Trust	trifluralin	Dinitroaniline	3
Tupersan	siduron	Urea	7
Turflon Ester	triclopyr	pyridinecarboxylic acid	4
Ultra Blazer	acifluorfen	Diphenylether	14
Valor	flumioxazin	N-phenylphthalimide	14
Valor XLT	flumioxazin + chlorimuron	N-phenylphthalimide + sulfonylurea	14 + 2
Vanquish	dicamba	Benzoic acid	4
Velocity	Bispyribac-sodium	pyrimidunyloxybenzoic	2

Velpar	Hexazinone	Triazinone	5
Vision	dicamba	Benzoic acid	4
Volley	acetochlor	Chloroacetamide	15
Volley ATZ	acetochlor + atrazine	Chloroacetamide + triazine	15 + 5
Volunteer	clethodim	Cyclohexanedione	1
Weedmaster	2,4-D + dicamba	Phenoxy-carboxylic acid + benzoic acid	4 + 4
Yukon	halosulfuron + dicamba	Sulfonylurea + benzoic acid	2 + 4
2,4-D (numerous brands)	2,4-D	Phenoxy-carboxylic acid	4
2,4-DB (numerous brands)	2,4-DB	Phenoxy-carboxylic acid	4

[1]Modes of Action

1 ACCase inhibition
2 ALS inhibition
3 Microtubule assembly inhibition
4 Synthetic auxin
5 Photosystem II inhibition (different binding site than Groups 6 and 7)
6 Photosystem II inhibition (different binding site than Groups 5 and 7)
7 Photosystem II inhibition (different binding site than Groups 5 and 6)
8 Inhibition of lipid synthesis (not ACCase inhibition)
9 ESP synthase inhibition
10 Glutamine synthase inhibition
12 Inhibition of carotenoid biosynthesis at phytoene desaturase (PDS)
13 Inhibition of carotenoid biosynthesis (unknown target)
14 PPO inhibition
15 Inhibition of very long-chain fatty acids
16 Unknown mode of action
17 Unknown mode of action
19 Auxin transport inhibition
21 Inhibitor of cell wall synthesis site B
22 Photosystem I electron transfer
27 Inhibition of HPPD

Application Methods

Herbicides can be applied by several methods and at various times during the year. The following terms may be found on herbicide labels pertaining to their use.

1. **Preplant Incorporated (PPI)**

   Herbicides in this group must be mixed into the surface soil before planting in order to achieve good weed control. Usually, herbicides that must be incorporated in the soil are highly volatile. Without incorporation, these herbicides would be lost into the air as a gas. Read and follow the herbicide label for specific instructions regarding incorporation. Examples of PPI herbicides are Treflan, Sutan+ and Fradicane Extra.

2. **Preemergence**

   Herbicides in this group are usually applied immediately after planting. Preemergence means that the herbicide is applied after the crop seeds are planted but before the crop and weeds have emerged from the soil. This group of herbicides usually needs a rain within a few days after application to move the herbicide from the soil surface down into the top layer of the soil where most weed seeds are located. Some typical herbicides are Lasso, Dual, Lorox, AAtrex and Bladex.

3. **Over-lay Treatments (Split Applications)**

   This is a combination of the two types of application already discussed. A preplant incorporated herbicide is applied, the crop planted, and a preemergence herbicide is then applied. This practice is used to achieve a broader spectrum of weed control.

4. **Tank Mixtures**

   The application of herbicides mixed together in the sprayer tank is a common practice. Herbicides are also applied in combination with liquid fertilizer. When mixing herbicides or other pesticides in the spray tank, be certain to follow label recommendations and precautions. Specific directions for tank mixing of herbicides are frequently listed on the label.

5. **Postemergence**

This group of herbicides is applied after the weeds and crop have emerged from the soil. These treatments can be applied in either a broadcast or directed fashion. When applying postemergence herbicides, it is necessary to have maximum coverage of the weed with the spray solution. Surfactants are often used with postemergence herbicides to enhance control. For specific gallonages required and the amount, if any, of surfactant required, consult the label.

6. **Selective Application Equipment**

This type of postemergence application of herbicides is based upon a height differential between weeds and the crop. The herbicide is usually directed away from the crop and onto the weeds. For example, when the weeds extend above the soybean canopy Roundup can be applied with a rope wick or other wiper type applicators.

Hand-held spray equipment

Purchasing the equipment

- Hand-pump backpack sprayer, 3 to 4 gallon capacity. Many brands – Solo, Field King, SP Systems, etc., $80 to $150. Before you buy a sprayer, make sure you can get spare parts and a boom for it. Look for the following features:
  - built-in pressure regulator
  - diaphragm pump (better than a piston pump)
  - switchable arm

- CO_2 backpack sprayer. More expensive, but versatile and very consistent; the best choice for research or full-time use. Available through R&D Sprayers (co2sprayers.com).

- Spray boom – at least 3 nozzles, 16 to 20 inches apart. $35 to $90.

- get flat-fan, 80-degree nozzles made of brass or steel (8002XR is a good type)
- rear-mounted booms are available

➢ Accessories – measuring jug, dye tablets, flags, metronome

Look at local farm supply stores or Ben Meadows Company (benmeadows.com), Forestry Suppliers (forestry-suppliers.com), R&D Sprayers (co2sprayers.com), or others.

Making the application

Get to know the spray boom.
- select a good pressure
- spray on concrete to see how high to

hold the boom Calibrate!
Use flags or dye to keep track of your application.
- put a line of flags on each side of the field, spaced as far apart as your spray swath
- go directly toward the opposite flag
- pull the flags after you cross them to avoid confusion

Make sure the chemical gets mixed in as you fill the tank. Keep the spray solution mixed.
When you need to refill, disconnect the wand and set it down, or place a flag. For spot treatments, use a percent solution; spray to wet, not to runoff.

Herbicide Mode-Of-Action Summary

The mode-of-action is the overall manner in which a herbicide affects a plant at the tissue or cellular level. Herbicides with the same mode-of- action will have the same translocation (movement) pattern and produce similar injury symptoms. Selectivity on crops and weeds, behaviour in the soil and use patterns are less predictable, but are often similar for herbicides with the same mode-of-action. This publication organizes herbicides into those which are applied to foliage (many of these are applied to soil as well) and those herbicides applied almost strictly to soil. The foliar applied groups are then divided into three categories according to movement through the plant:

1. Symplastically translocated (source to sink capable of downward movement),
2. Apoplastically translocated (capable of only upward movement),
3. Those which do not move appreciably (kill very quickly).

Each translocation group is subdivided into mode-of-action groups which are further categorized by herbicide chemistry group. Strictly soil applied herbicides are divided into mode-of-action and then into herbicide chemistry groups.

Plants are complex organisms with well-defined structures in which multitudes of vital (living) processes take place in well ordered and integrated sequences. Plants are made up of organs (root, stem, leaf, and flower); organs consist of tissues (meristems, conducting, photosynthetic, structural); and tissues are made up of cells. Plant cells contain subunits including walls, membrane systems (golgi, plasma membrane, nuclear membrane, endoplasmic reticulum) and organelles (mitochondria, nucleus, chloroplasts), and undifferentiated cytoplasm.

Some vital metabolic plant processes include photosynthesis (capture of light energy and carbohydrate synthesis), amino acid and protein synthesis, fat (lipid) synthesis, pigment synthesis, nucleic acid synthesis (RNA - DNA essential to information storage and transfer), respiration (oxidation of carbohydrate to provide CO_2 and usable energy), energy transfer (nucleic acids) and maintenance of membrane integrity. Other vital processes include growth and differentiation, mitosis (cell division) in plant meristems, meiosis (division resulting in gamete and seed formation), uptake of ions and molecules, translocation of ions and molecules, and transpiration. One or more of the vital processes must be disrupted in order for a herbicide to kill a weed.

I. Foliar Applied Herbicides

A. Downwardly Mobile Herbicides [Symplastically Translocated (leaf to growing points)]

These herbicides are capable of moving from leaves (sources of sugar production) with sugars to sites of metabolic activity (sinks of sugar utilization) such as underground meristems (root tips), shoot meristems (shoot tips), storage organs and other live tissues. Since movement to sites is essential for continued plant growth, these herbicides have the potential to kill simple perennial and creeping perennial weeds with only one or two foliar applications.

Symptoms are evident on new growth first. Pigment loss (yellow or white), stoppage of growth, and distorted (malformed) new growth are typical symptoms. Most injury appears only after several days or weeks. Plants die slowly. Herbicides in this group are usually molecular (non- charged) at low pHs found in the cell walls and negatively charged at higher pHs encountered in the cytoplasm of leaf sieve cells of the phloem (the ionization inside the cytoplasm of the phloem accounts for trapping and movement of these herbicides).

1. Auxin Growth Regulators

The effects associated with auxins help set them apart from other downwardly mobile herbicides. Bending and twisting of leaves and stems is evident almost immediately after application. Delayed symptom development includes root formation on dicot stems; misshapened leaves, stems, and flowers; and abnormal roots.

Soil activity varies from almost none to long residual depending on herbicide and dose.

Auxin growth regulator herbicides are used for control of annual, simple perennial, and creeping perennial broadleaves in grass crops (corn, small grains, sorghum, turf, pastures, sodded roadsides and rangeland) and in non-crop situations. All are organic acids which take on a negative charge after ionization of acids and salts. Esters are hydrolyzed to acids or salts in both plants and soils. Injury to off-target vegetation is a major problem associated with these herbicides.

Common Name	Trade Name
Phenoxyaliphatic Acid Herbicides	
2,4-D	

2,4-DB	
MCPP	(mecoprop)
MCPA	
2,4-DP	(dichlorprop)

Benzoic Acids

dicamba	BANVEL/ CLARITY/ VANQUISH/ VETERAN

Picolinic Acids (Pyridines) and Relatives

picloram	TORDON
clopyralid	STINGER/ LONTREL
triclopyr	GARLON/ TURFLON
fluroxypyr	STARANE

2. Amino Acid Inhibitors (Aromatic)

Glyphosate and sulfosate are the compounds with this mode of action. Uses are limited to foliar applications only, since these chemicals are rapidly inactivated in the soil. Symptoms include yellowing of new growth and death of treated plants in days to weeks. These relatively nonselective compounds control annual grasses, annual broadleaves, johnsongrass, quackgrass, yellow nutsedge, cool season pasture and turf grasses, cattail, Canada thistle, hemp dogbane, Jerusalem artichoke, poison ivy, and multiflora rose. Glyphosate tolerant cultivars of soybeans (Roundup Ready), corn, and other crops are currently being marketed. Corn and other glyphosate tolerant crops are being tested for future release.

Common Name	**Trade Name**
glyphosate	ROUNDUP ULTRA/ RODEO/ACCORD
sulfosate	TOUCHDOWN

3. Amino Acid Inhibitors [Branched-chain (AHAS/ALS)]

Several groups of different chemistry have this same mode of action. Shoot meristems cease growth; yellow, pink and purple symptoms appear; roots tend to develop poorly; and the secondary roots are shortened and all nearly the same length producing a "bottlebrush" appearance. Complete symptom development is very slow and requires two to three weeks or more. Late postemergence applications of some of these herbicides used on corn may result in malformed (bottle shaped) ears.

Imidazolinones

Weed control in soybeans, alfalfa, wheat, barley, and non-crop situations is the major use of these compounds. Compounds are residual (weeks) to long-residual (several months) depending on herbicide dose. Dry weather and cool temperatures in particular and possibly low pH and high organic matter contribute to persistence in the soil. Imidazolinone tolerant corn cultivars are being marketed for use with imazethapyr.

Common Name	Trade Name
imazquin	SCEPTER
imazethapyr	PURSUIT
imazapyr	ARSENAL/ CHOPPER

Sulfonylureas

Sulfonylurea herbicides are applied preplant incorporated, preemergence, and postemergence at doses of 0.5 to 6 ounces active ingredient per acre. This herbicide group provides selective control of wild garlic and Canada thistle in small grains; broadleaf weeds in soybeans; johnsongrass, shattercane, quackgrass and wirestem muhly in corn; and weeds in conifers, hardwoods and pastures. Several compounds are used for general vegetation control on non-crop sites. High soil pH greatly increases persistence since only biodegradation takes place at higher soil pHs. At soil pHs below 6.8, chemical degradation occurs in addition to biodegradation and speeds inactivation. Sulfonylurea tolerant soybeans are available to farmers.

Common Name	**Trade Name**
chlorimuron	CLASSIC
chlorsulfuron	GLEAN/ TELAR
nicosulfuron	ACCENT
primisulfuron	BEACON
thifensulfuron	HARMONY PINNACLE
tribenuron	EXPRESS
sulfometuron	OUST
metsulfuron	ALLY
halosulfuron	PERMIT/ MANAGE

Sulfonanilides

Selective soil or foliar applied for control of annual broadleaf weeds in corn or soil applied treatments in soybeans.

flumetsulam	BROADSTRIKE

4. Chlorophyll/Carotenoid Pigment Inhibitors

Vivid white new growth, sometimes tinged with pink or purple, characterize the symptoms associated with the pigment inhibitors. New growth initially appears normal except for the conspicuous lack of green and yellow pigments. Uses include, selective weed control in soybeans and cotton, poison ivy control, general vegetation control and aquatic weed control.

Amitrole is the only compound of this group which moves well in the symplast, however other compounds in the group show initial movement into shoot tips causing new growth to be devoid of green and yellow pigments.

Common Name	**Trade Name**
clomazone	COMMAND
amitrole	AMITROL-T

norflurazon	ZORIAL/ SOLICAM
fluridone	SONAR

5. Grass Meristem Destroyers (Lipid Biosynthesis Inhibitors)

All provide the same symptoms on grass species; namely discoloration and disintegration of meristematic tissue at and above the nodes, including nodes of rhizomes. Leaves yellow, redden and sometimes wilt. Seedling grasses tend to lodge by breaking over at the soil. These herbicides have the potential to be used for selective removal of most grass species from any non-grass crop. There is also some selectivity among grass species (particularly with the aryloxyphenoxypropionates in cool season grasses). The grass meristem destroyers should be used early postemergence on seedling grasses, and postemergence but before the boot stage (the seedhead detectable in the top leaf sheath) on established perennial grasses. Mixing with postemergence broadleaf herbicides frequently results in reduced grass control. When used under less than ideal conditions (no-till, open crop canopies and drought) two applications per season are frequently required.

These compounds are more active postemergence (foliar) than soil applied. At normally used postemergence doses, soil activity is marginal or lacking.

Aryloxyphenoxypropionates

Common Name	**Trade Name**
fenoxaprop	WHIP/HORIZON/ OPTION/ACCLAIM
fluazifop-P	FUSILADE /2000/FUSILADE DX
quizalofop	ASSURE II

Cyclohexanediones

clethodim	SELECT
sethoxydim	POAST/ POAST PLUS

B. Non Translocated (Contact Herbicides)

Cell Membrane Destroyers

Compounds in this group result in rapid disruption of cell membranes and very rapid kill. The bipyridyliums and the diphenyl ethers penetrate into the cytoplasm, cause the formation of peroxides and free electrons (light is required) which destroy the cell membranes almost immediately. Herbicidal oils dissolve membranes directly. Rapid destruction of cell membranes prevents translocation to other regions of the plant. Severe injury is evident hours after application, first as water-soaked areas which later turn yellow or brown. Maximum kill is attained in a week or less. Partial coverage of a plant with spray results in spotting and/or partial shoot kill. New growth on surviving plants will be normal in appearance. Foliar activity alone can provide only shoot kill.

Bipyridyliums

These foliar applied, strongly cationic, relatively toxic herbicides are used postemergence only. Extremely strong binding to clay prevents activity for weed control or leaching in the soil. Only shoot kill can be expected. Liquids with suspended colloids (muddy water, slurry fertilizers) cause inactivation. These herbicides are used for general shoot kill in numerous situations including burn down in conservation tillage systems and preharvest desiccation. Diquat is used for control of aquatic weeds.

Common Name	Trade Name
paraquat	GRAMOXONE
diquat	DIQUAT/REWARD

Diphenyl ethers (nitrophenyl ethers)

These herbicides have both foliar and soil activity. They mostly control broadleaves. Acifluorfen is labeled for postemergence applications to soybeans, peanuts, and rice. Fomesafen and lactofen are similar to acifluorfen. Although bronzing or burning of soybean leaf tissue is evident after application, yield is rarely affected. Oxyfluorfen is used preemergence for cole crops and postemergence for mint, onions and conifer nurseries. This herbicide group is relatively unaffected by soil texture and organic matter.

Common Name	Trade Name

acifluorfen	BLAZER
fomesafen	REFLEX
lactofen	COBRA
oxyfluorfen	GOAL

Other post emergence herbicides

Bentazon is used only post emergence in large seeded legumes and some grass crops for control of annual broadleaf weeds and yellow nut sedge and shoot removal of perennial broadleaf weeds. This compound inhibits photosynthesis in the target plant.

Glufosinate is applied post emergence for control of annuals prior to crop establishment, for noncrop areas and for selective directed placement in specialty crops (apples, grapes, tree nuts). There is no soil activity. The inhibition of the glutamine synthetase enzyme in the effected plant results in the decrease of several amino acids which eventually leads to cell membrane disruption and death of the cell. Symptoms of the plant include chlorosis (yellowing) followed by necrosis (dead tissue) 3 to 5 days after herbicide application. Glufosinate tolerant cultivars of rice, soybeans, and corn are being tested.

Common Name	**Trade Name**
bentazon	BASAGRAN
glufosinate	IGNITE/RELY/ FINALE/LIBERTY

C. Upwardly Mobile Only Herbicides (Apoplastically Translocated)

Photosynthetic Inhibitors

These herbicides translocate only apoplastically. Movement is upward with the transpiration stream (water moving through the plant from the soil and evaporating into the atmosphere at the leaf surfaces).

Symptoms develop from bottom to top on plant shoots (older leaves show most injury; newer leaves least injury). Chlorosis first appears between leaf veins and along the margins which is later followed by necrosis of the tissue. Any potential control of established perennials must come from continued soil uptake and not movement downward through the plant from the shoots. Foliar activity alone can provide only shoot kill.

Herbicides in these chemical groups have excellent soil activity. Most have foliar activity as well. These herbicides are used preplant incorporated, preemergence, and to a limited extent early postemergence, for selective control of weeds in annual and established perennial crops. Crops include corn, soybeans, potatoes, celery, parsnips, carrots, cotton, alfalfa, asparagus, mint, and woody species. They are also used for brush in pastures, rangeland, and non-cropland and for general vegetation control. Soil persistence varies from weeks to months depending on compound and dose and soil pH. Soil mobility varies from low to high depending on the compound and soil characteristics.

Triazines

Major herbicides for weeds in corn, they are also used in sorghum, numerous woody species, and for total vegetation control. Use for aquatics has been discontinued. Detection in and public concern regarding surface and ground water may result in severe restrictions on use of the triazine herbicides.

Common Name	**Trade Name**
atrazine	AATREX/Atrazines
simazine	PRINCEP
cyanazine	BLADEX
prometon	PRAMITOL
metribuzin	SENCOR/LEXONE
hexazinone	VELPAR
Uracils	
terbacil	SINBAR
bromacil	HYVAR
Phenylureas	
linuron	LOROX/LINEX
diuron	KARMEX
tebuthiuron	SPIKE
Others (not typical)	
bentazon	BASAGRAN
bromoxynil	BUCTRIL
pyridate	TOUGH/LENTAGRAN

II. Soil Applied Herbicides

Cell Division Inhibitors

Root Inhibitors

These herbicide groups have little or no foliar activity and are applied mostly preplant incorporated and preemergence for control of seedling grasses and some annual broadleaves in soybeans, peanuts, dry beans, cole crops, cotton, alfalfa, clovers, lettuce, tobacco, herbaceous ornamentals, established turf, and in woody species (nurseries, orchards, grapes, Christmas trees, etc.).

Dinitroanilines (Dinitrobenzenamines)

These herbicides inhibit the steps in plant cell division responsible for chromosome separation and cell wall formation. Roots are relatively few in number and club shaped. Except for oryzalin, these compounds have water solubility less than one part per million. They bind to soil colloids and are unlikely to leach. Losses occur through volatilization and photodegradation on soil surfaces. Incorporation into the soil by mechanical mixing or by overhead irrigation soon after application is routinely suggested. These root inhibitors do not translocate.

Common Name	Trade Name
trifluralin	TREFLAN
benefin	BALAN
prodiamine	BARRICADE/ ENDURANCE
oryzalin	SURFLAN
pendimethalin	PROWL/PENTAGON STOMP/PENDULUM
ethalfluralin	SONALAN

Miscellaneous Herbicides

DCPA is labeled soil applied for seedling grass control in large seeded legumes, cotton, cole crops, onions, garlics, potatoes, other vegetables, established turf, herbaceous ornamentals, and small fruits.

Siduron is labeled soil applied for seedling grass control in newly seeded or newly sprigged turf and established turf. It removes annual grass competition from spring established turf.

Common Name	Trade Name
DCPA	DACTHAL
siduron	TUPERSAN

2. Shoot Inhibitors

The shoot inhibitors are soil applied for control of seedling grasses, some broadleaves and suppression of some perennials from tubers and rhizomes. Injury appears as malformed (twisted), dark green shoots and leaves on injured young plants. Grass crops with some tolerance to these compounds can be protected from injury with other chemicals [safeners (protectants)]. Crops include corn, large seeded legumes, small seeded legumes, beets, spinach, tomatoes, potatoes, and ornamentals.

Thiocarbamates (Carbamothioates)

This group of very volatile herbicides is used preplant incorporated. They persist in the soil for two to six weeks and are particularly effective for control of seedling grasses including johnsongrass and shattercane.

Common Name	Trade Name
EPTC	EPTAM/ERADICANE
butylate	SUTAN+
pebulate	TILLAM
cycloate	RO-NEET

Substituted Amides (Chloroacetamides)

These are the major preemergence herbicides for seedling grass control in corn and soybeans in the Eastern Corn-belt. Several provide decent control of seedling grasses in higher organic matter soils. Most are labeled for preplant incorporated application. Most of these herbicides control yellow nutsedge and black nightshade. Typical persistence in the soil is 10 to 15 weeks.

Common Name	Trade Name
acetochlor	HARNESS/SURPASS/ TOPNOTCH
alachlor	LASSO/MICRO-TECH/PARTNER
metolachlor	DUAL/DUAL II

propachlor	RAMROD
dimethenamid	FRONTIER

3. Shoot and Root Inhibitors

Preplant incorporated, preemergence and sometimes early postemergence for control of annual grasses, and some annual broadleaves in small seeded legumes, lettuce, established woody species, established turf, strawberries, established herbaceous perennials, tomatoes, cole crops, cotton, cucurbits, peppers, and tobacco.

Common Name	**Trade Name**
bensulide	BETASAN/ BENSULIDE/PREFAR
napropamide	DEVRINOL
pronamide	KERB
dichlobenil	CASORON
dithiopyr	DIMENSION

MODE OF ACTION

The term mode of action refers to the sequence of events from absorption into plants to plant death. The mode of action of the herbicide influences how the herbicide is applied. For example, contact herbicides that disrupt cell membranes, such as acifluorfen (Blazer) or paraquat (Gramoxone Extra), need to be applied post emergence to leaf tissue in order to be effective. Seedling growth inhibitors, such as trifluralin (Treflan) and alachlor (Lasso), need to be applied to the soil to effectively control newly germinated seedlings.To be effective, herbicides must

1) adequately contact plants;

2) be absorbed by plants;

3) move within the plants to the site of action, without being deactivated; and

4) reach toxic levels at the site of action. The application method used, whether pre plant incorporated, pre emergence, or post emergence, determines whether the herbicide will contact germinating seedlings, roots, shoots, or leaves of plants.

The herbicide families listed below are grouped on the basis of how they affect plants (their mode of action)

1. The Growth Regulator Herbicides (2,4-D, MCPP, dicamba, and triclopyr). These are mostly foliar applied herbicides which are systemic and translocate in both the xylem and phloem of the plant. They mimic natural plant auxins, causing abnormal growth and disruption of the conductive tissues of the plant. The injury from this family of herbicides consists of twisted, malformed leaves and stems.

2. The inhibitors of amino acid synthesis (glyphosate, halosulfuron, imazethapyr, and sulfometuron). Both foliar and soil applied herbicides are in this family. Glyphosate translocates in the phloem with photosynthate produced in the leaves. Others in this family move readily after root or foliar absorption. These herbicides inhibit certain enzymes critical to the production of amino acids. Amino acids are the building blocks of proteins. Once protein production stops, growth stops. Symptoms are stunting and symptoms associated with lack of critical proteins.

3. Cell membrane disrupters - with soil activity (oxyfluorfen, lactofen, and acifluorfen). Soil and foliar applied with limited movement in soil. These herbicides enter the plant through leaves, stems, and roots, but are limited in their movement once they enter the plant. Membrane damage is due to lipid peroxidation. Symptoms are necrosis of leaves and stem.

4. Lipid biosynthesis inhibitors (diclofop, fluazifop, sethoxydim, and clethodim). Foliar applied Diclofop has both soil and foliar activity. Herbicides in this family move in both the xylem and phloem of the plant and inhibit enzymes critical in the production of lipids. Lipids are necessary to form plant membranes which are essential to growth and metabolic processes. Symptoms include stunting and death of tissue within the growing points of plants.

5. Pigment inhibitors (norflurazon, fluridone, and amitrol). Soil applied and move in the xylem except amitrol, which moves in both phloem and xylem. These herbicides inhibit carotinoid biosyntehsis, leaving chlorophyll unprotected from photooxidation. This results in foliage which lacks color. Symptoms include albino or bleached appearance of foliage.

6. Growth inhibitors of shoots (thiocarbamate herbicides including: EPTC, cycloate, pebulate, and molinate). Soil applied and somewhat volatile, requiring incorporation. Enter the plant through the roots and translocated through the xylem with the transpiration stream to the growing points in the shoot. Mode of action is unclear, but affects developing leaves in growing points of susceptible plants. Symptoms include stunting and distortion of seedling leaves.

7. Herbicides which disrupt cell division (trifluralin, DCPA, dithiopyr, oryzalin, pronamide, pendimethalin, and napropamide). All are soil applied, with limited movement in the soil. Absorbed through roots or emerging shoot tips. Once absorption takes place, movement is limited (site of action is near the site of absorption). These herbicides inhibit cell division or mitosis, except pronamide and napropamide which stop cell division before mitosis. Symptoms include stunting and swollen root tips.

8. Cell membrane disrupters - no soil activity (paraquat, diquat, glufosinate, acids, oils, soaps). These herbicides are foliar applied with no soil activity. They enter the plant through the leaves and stems and do not move significantly within the plant once absorbed. These herbicides either act directly on cell membranes (acids, soaps. oils) or react with a plant process to form destructive compounds which result in membrane damage. Symptoms include rapid necrosis of the leaves and stem.

9. Inhibitors of photosynthesis (atrazine, simazine, metribuzin, cyanazine, prometryn, diuron, linuron, tebuthiuron, and bromacil). These are soil applied herbicides, however, all except simazine also have foliar activity. They move readily in the plant in the xylem with the transpiration stream where they concentrate in the leaves at the site of photosynthesis. Once there they block the electron transport system of photosynthesis, causing a build up of destructive high energy products which destroy chlorophyll and ultimately the leaf tissues. Symptoms include chlorotic (yellowed) leaves which become necrotic.

Herbicide Resistance

Herbicide resistance probably develops through the selection of naturally occurring biotypes of weeds exposed to a particular family of herbicides over a period of years. A biotype is a population of plants within the same species that has specific traits in common. Resistant plants survive, go to seed, and create new generations of herbicide resistant weeds.

Mechanisms for resistance vary depending on herbicide family. Resistant biotypes may have slight biochemical differences from their susceptible counterparts that eliminate sensitivity to certain herbicides. Also, while photosynthesis is inhibited in triazine herbicide susceptible biotypes, because of a slight change in a chloroplast protein, triazine resistant biotypes are able to continue normal photosynthesis upon exposure to triazine herbicides. The potential for developing herbicide resistant biotypes is greatest when an herbicide has a single site of action.

Regardless of the mechanism for resistance, becoming familiar with the herbicide mode of action can help design programs that prevent the introduction and spread of herbicide resistant weeds. Management programs for herbicide resistance should emphasize an integrated approach that stresses prevention. Dependence on a single strategy or herbicide family for managing weeds will surely increase the likelihood of additional herbicide resistance problems in the future. Some guidelines for an integrated approach to managing herbicide resistant weeds are given below.

Strategies for preventing or managing herbicide resistance

- Practice crop rotation.
- Rotate herbicide families and use herbicides with different modes of action.
- Use herbicide mixtures with different modes of action.
- Control weedy escapes and practice good sanitation to prevent the spread of resistant weeds.

- Integrate cultural, mechanical, and chemical weed control methods.

Effect of sub lethal dosage

When herbicides are applied on the soil, neighboring fields may be affected by drift. The high doses of herbicides applied to previous crop may be harmful to the succeeding crop. However, these sub lethal doses may be occasionally helpful based on crop and the herbicide used.

Herbicides show stimulatory effects on crops and toxic effects on sensitive crops even at sub lethal doses. Which show stimulatory effects are phenoxys, triazines, urea’s and uracils. In fact, 2, 4-D was first used for its hormonal effect before its herbicidal properties were discovered.

Phenoxy herbicides have growth promoting activities at lower doses similar to indolacetic acid (IAA). They are active at the meristamatic tissues causing increased metabolic activities and consequently higher grain protein content and yield. Protein content of wheat is increased by dusting 5g/ha of 2,4-D mixed with micronutrients like iron and copper. Even higher dose, say 0.5 to 1.3 kg/ha applied to the soil as herbicide before sowing increases the protein content of wheat. The other crops which show stimulatory effect due to herbicide application are beans, potato, sugarcane, soybean etc.

Among triazines, simazine and atrazine produce favourable effects at sub lethal doses. They increase nutrient absorption, chlorophyll and protein content. Simazine at 0.06 ppm increased nutrient uptake and yield of maize, but at 0.3 ppm concentration the yield decreased. The sub lethal effects caused by drifts are rarely toxic except to sensitive crops. Spray drift of 2,4 D causes epinasty on cotton plants.

Amitrole at 10 to 100 ppm sprayed on tobacco or wheat causes chlorosis due to chloroplast malformation and reduction in chlorophyll and carotenoids. Soil residues of herbicides appilied to the previous crops may affect germination of sensitive crops.

Selectivity and mode of action of herbicide

Selective herbicides have been used extensively since the introduction of 2,4-D in the late '40s. They have been one of the miracles of modem agriculture, releasing thousands of people from the drudgery of hand weeding. A selective herbicide is one that kills or retards the growth of an unwanted plant or "weed" while causing little or no injury to desirable species. 2,4- D used in turf will kill many of the broadleaf weeds that infest turf while not significantly injuring the turf grass. But selectivity is a fickle, dynamic process. Excessive rates of 2,4-D applied to stressed turf grass may injure the turf. Selectivity has always depended on proper herbicide application. Normally herbicides work selectively within a given rate of application. Too little herbicide and no weed control, too much and crop injury may occur. But selectivity is more complex than this. It is a dynamic process that involves the interaction of the plant, the herbicide, and the environment.

I. The Plant

Factors that involve plant response include: genetic inheritance, age, growth rate, morphology, physiology, and biochemistry. The genetic make-up of a plant determines how that plant responds to herbicides and its environment. The age of the plant often determines how well an herbicide works, older plants are generally much more difficult to control than seedlings.

Pre emergence herbicides often work only on plants during the germination process and will have little effect on older plants. Plants which are growing rapidly are usually more susceptible to herbicides. The morphology of a plant can help to determine its susceptibility to herbicides. Annual weeds in a deep rooted crop can be controlled because the herbicide is concentrated in the first inch of soil where the weeds and weed seeds are. Weeds with exposed growing points may be killed by contact sprays, while grasses with protected growing points may be burned back, but escape permanent injury. Certain leaf properties can allow better spray retention and thus better kill (broadleaf species vs. grasses or hairy vs. smooth leaves). Sprays tend to be retained on pigweed and mustard leaves and bounce off of onion or grass species.

The physiology of a plant can determine how much of an herbicide will be absorbed onto the plant and the speed with which it is transported to its site of action. Plants with thick waxy cuticles or hairy leaf surfaces may not absorb sufficient herbicide to be injured. Wetting agents in herbicide formulations are used to combat these leaf characteristics and increase absorption. The transport rate of herbicides in plants varies. Usually susceptible plants transport herbicide more readily than resistant ones. Some plants can adsorb herbicides along the transport pathway, preventing them from reaching their site of action.

Biochemical reactions also account for selectivity. Most herbicides have a biochemical reaction within susceptible plants which accounts for their herbicidal activity. They may bind to critical enzymes within susceptible plants and block important metabolic processes (glyphosate), they may block photosynthesis (diuron) or respiration, or they may affect cell division (trifluralin). Herbicides may be absorbed as relatively innocuous chemicals (2,4-DB) and activated to deadly compounds (2,4-D) within susceptible plants. Other herbicides (atrazine) may be detoxified within some plants (com) while killing weeds which fail to metabolize the herbicide.

II. The Herbicide

Herbicides are quite specific in their structures as to whether or not herbicidal activity is possible. Slight changes in conformation or structure will alter herbicidal activity. Trifluralin and benefin differ in only a methyl group moved from one side of the molecule to the other, yet trifluralin is about twice as active as benefin. Esters of phenoxy (MCPP etc.) acids are usually much more active than are amines. The manner of formulation of an herbicide can affect its selectivity. The most extreme case of this might be granular formulations which bounce off desirable plants to reach the soil where they then limit germinating weeds. Other substances known as adjuvants or surfactants are often added to improve the application properties of a liquid formulation and increase activity. The manner in which an herbicide is applied can affect its selectivity.

When a broad-spectrum post emergence herbicide like glyphosate is applied as a shielded, directed, or wicked application within a susceptible crop, susceptible foliage is avoided and selectivity is achieved with this normally non-selective herbicide. Herbicides can be grouped into families based on the type of action that they have within affected plants **(their mode of action).**

III. The Environment

There are many ways that the environment interacts with herbicide selectivity. The soil determines how much of soil applied herbicides are available for activity. Sandy soils, with low organic content, are much more active and conversely less selective than clay soils with high organic content at a given rate of herbicide application.

Irrigation or rainfall amount and timing influence the depth to which herbicides may move in the soil and plant growth and stress, all of which can increase or decrease herbicide selectivity. Temperature affects the rate of herbicide transport, the rate of biochemical reactions, plant growth, plant stress, and ultimately herbicide selectivity. Wind, relative humidity, insects, plant pathogens, and nutritional status also affect plant growth and stress which can increase or decrease herbicide selectivity.

Fate of Herbicide

In the present day agriculture, herbicide use is increasing due to escalating labour cost, easy availability of herbicides, rapid weed control in cropped and non-cropped situations. In India, the herbicide use has increased tremendously during the last 10 years. Since herbicides are synthetic chemicals, therefore excessive and frequent use may cause herbicide residue problems, toxicity to plants, residual effects on succeeding or intercrops crops, harmful effects on non-targeted organisms, and health hazards to human beings and animals. Many herbicides are detected as bound residues and make them unavailable to the targets and contaminating the ecosystem in a number of ways. Therefore, monitoring of herbicide residues in plants, fishes, soil, water, and other commodities is very important. Fate of herbicide in soil depends on several processes such as absorption, volatilization, adsorption, leaching, runoff, photodecomposition, dissipation by microbial and chemical processes. Therefore, studies were conducted to determine persistence and herbicides residues in soil, water and crops including cereals, vegetables, pulses and fodders. Half-lives of herbicides were found to be 57–71 days for imidazoline, 13–60 days for phenylureas, 13–147 days for sulfonylureas, 12–58 days for triazines, 5–60 days for chloroacetinalides, 12–77 days for dinitroanilines, 19–29 days for diethyl-ethers, 19–24 days for thiocarbamates and 8–24 days for fop group of herbicides in the soil. Herbicide residues in about 80% samples were found below the detection limit (BDL). However, residues in 13.4% samples were found below the maximum residue limit (MRL), and 6.6% samples were detected above MRL values. At harvest, herbicides in various commodities were found either below MRL or BDL. Herbicide contamination of plants and natural waters was found to be infrequent and at low levels in the soils of central India

Process	**Consequence**	**Factors**
Movement (processes that relocate agrochemicals without changing their structure)		
Physical drift	Movement due to wind action	Wind speed, drop sizes
Volatilization	Loss due to evaporation from soils, plants, and waters	Vapor pressure, wind speed, temperature
Adsorption	Removal due to interaction with soils, plants, and sediments	Clay content, organic matter, moisture
Absorption	Uptake by plant roots or animal ingestion	Cell membrane transport, contact time
Leaching	Horizontal and vertical	Water content, soil texture,

movement downward through the soil	clay and organic matter contents	
Erosion	Wind and water action	Rainfall, wind speed, sizes of clay and organic matter
Degradation (processes that modify the chemical structure)		
Photochemical	Assorption of sunlight (i.e., ultraviolet radiation)	Chemical structure, intensity and duration of exposure
Microbial	Degradation by microorganisms	Environmental factors (pH, moisture, temperature) organic matter content
Chemical	Hydrolysis and redox reactions	pH modifications, same factors as microbial degradation
Metabolism	Adsorption by plants or animals	Adsorption capacity, metabolism, interactions with microorganisms

Movement and degradation processes of agrochemicals in the environment

Chemico-physical parameters affecting the fate of herbicides in soil

The fate of herbicides such as that of any organic molecule released into the environment is determined by their chemico-physical characteristics.

Solubility. The solubility of an herbicide is important in predicting its behaviour in water and its mobility in soil. Agrochemical water solubility is a function of temperature, pH, and ionic strength and is affected by the presence of other organic substances such as the dissolved organic matter (DOM) (Pierzynsky et al., 2000). Two methods are frequently used to estimate organic molecule solubility based on i) chemical structure (*Kps*) and ii) the *n*- octanol/water partition coefficient (*KOW*). n-Octanol/water coefficients are determined by the following equation which highlights that there is an inverse relationship between solubility and KOW:

$$K_{OW} = \frac{\text{concentration of organic chemical in octanol}}{} \left(\frac{mg}{} \right.$$

concentration of organic chemical in water mg —

Persistence. The persistence of an herbicide is defined as the time in which the molecule remains in the soil and is usually expressed as half-live. Half-live (t1/2) refers to the time required to halve the organic molecule concentration compared with its initial level.

Half-life values are important in understanding the potential environmental impact of a chemical; in fact, a molecule which degrades quickly, has a low t1/2 value and thus the impact of this species on the environment is reduced if the degradation products are harmless. On the contrary, the environmental impact of species with a high t1/2 value can be substantial even if the molecule is only moderately toxic.

The prediction of herbicide half-life and thus, its persistence in the environment is an important parameter in agronomic practice because it supplies information on the residual activity of agrochemicals which could cause damages to the successive crops.

For a first order reaction, the half-life is determined by the following equation:

$$t_{(1/2)} = 0.693/k$$

where k is the kinetic constant of the degradation reaction involving the agrochemical. *Volatilization.* Volatilization of organic molecules is responsible for the transfer of molecules from aquatic and soil environments into the atmosphere. As with the solubility, it is important to know the contribution of agrochemical volatilization in predicting its residual amount and thus, its persistence in the environment.

The volatilization of herbicides from waters depends on the chemical and physical properties of the molecules in question (e.g., vapour pressure and solubility), their interaction with suspended materials and sediments, the physical properties of the water bodies (depth, turbulence, and velocity) and any water-atmosphere interface properties.

The solubility of a gas dissolved in an aqueous solution is well defined by the Henry constant, calculated using the homonymous equation:

$K_H = P_{gas} / C_{aq}$

where K_H is the Henry constant, P_{gas} is the gas partial pressure and C_{aq} is its concentration in the aqueous phase. For high K_H values, the molecule prefers to leave the liquid phase in order to pass into the atmosphere. This constant is useful to describe the agrochemical fugacity from a water body but also from soil solid components which are always surrounded by water in adsorbed form.

The rate of volatilization can be indicated as half-life, which is the time required to halve the organic molecule concentration in water compared with its initial value. The volatilization half-lives of different molecules are reported in the table 2.

Factors that influence the volatility of organic molecules from soils include the chemical and physiochemical properties of the pollutant (i.e., vapour pressure, solubility, the structure and nature of the functional groups, and adsorption-desorption characteristics),concentration, soil properties (soil moisture content, porosity, density, and organic matter and clay contents) and environmental factors like temperature, humidity, and wind speed.

Volatilization	**Agrochemical**	***t1/2***
Low	Dieldrin	327 d
	3-bromo-1-propanol	390 d
Medium	Phenantrene	31 h
	Pentachlorophenol	17 d
	DDT	45 h
	Aldrin	68 h
	Lindane	115 d
High	Benzene	2.7 h
	Toluene	2.9 h
	O-xylene	3.2 h
	Carbon tetrachloride	3.7 h

Volatilization rates of some organic molecules (Pierzynsky et al., 2000).

Photolysis. Photochemical reactions involve sunlight radiation and play an important role in the degradation of molecules on soil surfaces and in aquatic environments. Photolysis in the soil is difficult to determine because of the heterogeneous nature of soils and low sunlight penetration. Nevertheless, it is an important herbicide degradation process in soil since it is always active.

In water as well as in soil, photolysis can occur either by direct or indirect processes. In direct photolysis, sunlight is absorbed directly by organic molecules which alter its chemical structure. The indirect process occurs in the presence of natural photosensitive species such as nitrates or humic acids which can absorb the light and subsequently transfer excitation energy to the organic molecule.

Biodegradation. Herbicide biodegradation is due to microorganism activity and is a function of those properties which influence microbial activity such as temperature and pH: a temperature or pH decrease slows down the biotic degradation rate since under such conditions microbial activity is reduced. This could explain the presence of certain molecules such as antibiotics, in the deeper layers of soils and waters (Gavalchin & Katz,1994; Van Dijk & Keukens, 2000).

Adsorption isotherms are built by measuring the residual concentrations of pollutant in aqueous solution at the equilibrium point, after the adsorption on soil of different initial concentrations. For each concentration point, the adsorbed molecule concentrations are determined by the difference between initial and equilibrium concentrations.

Adsorption isotherms. Adsorption isotherms of organic molecules are divided into four classes, according to the nature of the initial curve portion (Giles et al., 1960). The four classes are know as H (high affinity), L (Langmuir type), C (constant partition), and S (sigmoidal or with an “s” form) isotherms (Figure 2). The L curves are the best known: the initial curvature shows that as more sites in the substrate are filled, it becomes increasingly difficult for solute to find an available vacant site. The H isotherm is a special case of L curve, where the solute has a high affinity for the surface especially at low concentrations. The C curves are characterized by the constant partition of solute between the liquid and solid phase; the constant partition is independent of concentration right up to the maximum possible adsorption, where an abrupt change in the slope to a horizontal plateau occurs. The initial part of the S curves describes contrary conditions in comparison with the other isotherms: the more solute has already been adsorbed, the easier it is for additional amounts to become fixed. This implies a side-by-side association between adsorbed molecules, helping to hold them to the surface. This has been called “cooperative adsorption”.

Abiotic and biotic transformations. Both abiotic and biotic reactions are responsible for the transformation of herbicides in soils and waters. One of the two processes may be dominant, but usually both of these participate simultaneously in molecule degradation. The principal abiotic reactions that occur in water are hydrolysis, oxidation-reduction, and photolysis; in sediments, hydrolysis and redox reactions may prevail. Redox reactions in aquatic environments can be mediated by direct or indirect photolysis or catalyzed by metal species. In soil, abiotic reactions occur in the liquid phase (i.e. soil solution) and at the solid-liquid interface. In soil solution, hydrolysis and redox reactions are the most common abiotic transformations; these reactions are catalyzed by clays, organic matter and metal oxides.

Soil inorganic phase: clay minerals

Soil solid phases are almost totally characterized by inorganic components (fragments of rocks, primary and secondary minerals, amorphous materials); the organic component is only a small fraction.

Minerals are the most diffuse inorganic species in the lithosphere. From a chemical point of view, they are classified as: i) silicates formed by oxygen and silicon and ii) nonsilicates, such as oxides, carbonates, phosphates, sulphates.

Silicon tetrahedron is the building unit of silicates: different classes of silicates are obtained by the polymerization of building units.

Layered aluminosilicate minerals, known as clay minerals, have a profound influence on many soil chemical reactions because of their high active surface area. They have regular layers of tetrahedral and octahedral sheets: tetrahedral sheets are comprised of silicon and oxygen atoms with three out of every four oxygen atoms shared between adjacent tetrahedra. There are two types of octahedral sheets: dioctahedral and trioctahedral. Dioctahedral sheets have two out of every three octahedral sites occupied, most often by the trivalent Al cation. Trioctahedral sheets have all octahedral sites occupied by divalent cations, which are commonly Mg ions. Clays have structures that are either 1:1, 2:1, or 2:1:1 layers of tetrahedral and octahedral sheets. 1:1 clay minerals have one tetrahedral and one octahedral sheet held together by sharing an apical tetrahedral oxygen. 2:1 clay minerals have an octahedral sheet posed between two tetrahedral sheets. 2:1:1 layered clays are similar to 2:1 clays with an additional dioctahedral or trioctahedral sheet between the 2:1 layers .

. Soil organic matter

The organic components of soils are characterized by:

- vegetable and animal residues which are partially degraded and *in transformation*;
- the biomass of living organisms;
- materials of the neogenesis.

Vegetable and animal residues are slowly decomposed by microbial attack on molecular and ionic compounds which can be transformed by polycondensation in macromolecules with complex and unknown chemical structures: these are known as humic substances. Humic substances have colloidal dimensions, high specific areas and are able to adsorb molecules or ions. The dark colour of humic compounds promotes the sunlight radiation absorption and thus, the increase of soil temperature.

Organic matter plays an important role in the chemistry of soils: it covers the pores created by roots or pedofauna action by stabilizing the soil structure. Organic matter affects the water flow into the pores (capillary porosity): in fact, the coexistence of hydrophilic and hydrophobic properties in the same structure makes organic matter a material which is able to retain moisture or to repel the water by decreasing its flow along the pores. Moreover, organic matter forms macroscopic aggregates ("cements") with inorganic species (i.e. Fe and Al oxides and hydroxides) which stabilize the soil structure.

Finally, the organic matter can interact with agrochemicals by H-bondings, van der Waals forces, H_2O bridgings, and hydrophobic bondings.

5. Dissolved organic matter, DOM

Dissolved organic matter (DOM) is defined as “the amount of organic matter that is able to dissolve in the field conditions”. DOM plays an important role in the biogeochemistry of

carbon, nitrogen, and phosphorous, in pedogenesis and in the transport of pollutants in soils (Kalbitz et al., 2000).

The source of virtually all DOM in soils is photosynthesis; this includes both recent photosynthate (throughfall, leaf litter, root exudates, decaying fine roots) as weel as the leaching and decomposition of older, microbially processed soil organic matter. DOM ranges in age from hours to days, to decades and even up to thousands of years.

Sinks of DOM include microbial transformation and immobilization, mineralization (to CO_2, inorganic N, etc.), precipitation, and adsorption on mineral surfaces.

The effect of DOM on the fate of herbicides

The water solubility of herbicides is one of the most important physical properties controlling the transport and fate of chemicals in aquatic systems (Chiou et al., 1986). The formation of soluble complexes between agrochemicals and DOM can be considered responsible for the transport of pollutants towards water bodies. Previous studies have indicated that low concentrations of dissolved and/or suspended particulate-bound natural organic matter in water can significantly enhance the solubility and stability of many hydrophobic organic compounds, notably DDT and some polychlorobiphenyls (PCBs).

The water solubility enhancement of solutes characterized by low water solubility such as DDT, 2,4,5,2',5'-PCB, trichlorobenzene, and lindane, due to their interaction with the dissolved humic and fulvic acids extracted from soil and aquatic sediments. The effectiveness of DOM in enhancing solute solubility appears to be largely controlled by DOM molecular size and polarity.

The nature of DOM (exogenous or endogenous) influences the adsorption and desorption of dimefuron, atrazine and carbetamine. The authors observed that DOM chemico-physical properties, like organic carbon content, pH, and conductivity, strongly affect herbicide adsorption. Moreover, different DOM additions to soils (pretreatment with DOM solution before herbicide adsorption or preincubation of DOM solution with herbicide before soil addition) influences adsorption as a function of herbicide solubility. Increased adsorption of less soluble atrazine and dimefuron, after soil pretreatement with DOM solution, can be explained by an increase in soil adsorption capacity related to the increase of soil C content via adsorption of some organic compounds from DOM solutions. The fate of the highly soluble carbetamide is different: its adsorption decrease can be explained by the coverage of soil hydrophilic sites by DOM organic compounds adsorbed during the preincubation

Conclusions

The prediction of the movement and the fate of herbicides in soils represents an important strategy in limiting their environmental impact. The chemico-physical properties of herbicides affect their behaviour in soil and regulate their interaction mechanisms with organic and inorganic soil phases. Among these, dissolved organic matter plays an important role: DOM influences the mobility of herbicides by complex interactions that can facilitate or reduce the movement of chemicals along the soil profile.

The knowledge of soil phase characteristics and the mechanisms involved in herbicide transformation can help to understand the fate of herbicides in soil

Adjuvant

An adjuvant is any substance in a herbicide formulation or added to the spray tank to improve herbicidal activity or application characteristics.
Spray adjuvants are generally grouped into two broad categories–activator adjuvants and special purpose adjuvants.

Special purpose adjuvants:

- widen the range of conditions under which a given herbicide formulation is useful.
- may alter the physical characteristics of the spray solution.
- include compatibility agents, buffering agents, antifoam agents, and drift control agents.

Activator adjuvants:

- commonly are used to enhance postemergence herbicide performance.
- can increase herbicide activity, herbicide absorption into plant tissue, and rainfastness; can also decrease photodegradation of the herbicide.
- can alter the physical characteristics of the spray solution.
- include surfactants, crop oil concentrates, nitrogen fertilizers, spreader-stickers, wetting agents, and penetrants.

Surfactant:

- primarily reduces the surface tension between the spray droplet and the leaf surface.
- includes nonionic, anionic, cationic, and organosilicones.
- is required with many post-herbicides.
- is applied at 1/2 to 2 pt/acre or 0.25% volume/volume.

Crop oil concentrate:

- contains petroleum-based oils plus some nonionic surfactant.
- increases herbicide penetration and reduces surface tension.
- commonly is used with post-grass herbicides and atrazine.
- is applied at 1 to 3 pt/acre or 1% volume/volume.

Vegetable oil concentrates serve the same function as crop oil concentrates but are derived from vegetable-based oil.

Nitrogen fertilizer:

- can increase herbicide activity on certain weed species such as velvetleaf and certain grasses.

- improves the effectiveness of weak acid-type herbicides (e.g., Accent, Classic, Pursuit, Basagran, etc.).
- ammonium sulfate can reduce problems with hard water.
- generally is used in combination with surfactants or crop oil concentrates.
- application rate varies depending on product.

Adjuvant selection:

- should be primarily based on herbicide label.
- should consider percent active ingredient as well as cost.

Adjuvants are commonly used in agriculture to improve the performance of pesti- cides. Broadly defined, “an adjuvant is an ingredient that aids or modifies the action of the principal active ingredient.” The use of adjuvants with agricultural chemicals gener ally falls into two categories: (1) formulation adjuvants are present in the container when purchased by the dealer or grower; and (2) spray adjuvants are added along with the for- mulated product to a carrier such as water. The liquid that is sprayed over the top of a crop, weeds, or insect pest often will contain both formulation and spray adjuvants.

Formulation adjuvants are added to the active ingredient for a number of reasons in- cluding better mixing and handling, increased effectiveness and safety, better distribu- tion, and drift reduction. These traits are accomplished by altering the solubility, volatility, specific gravity, corrosiveness, shelf-life, compatibility, or spreading and pene- tration characteristics. With the large number of formulation options available (solutions, emulsions, wettable powders, flowables, granules, and encapsulated materials), adjuvants become even more important in assuring consistent performance.

Spray adjuvants are added to the tank to improve pesticide performance. Literally hundreds of chemical additives are now available that fall into this category. Spray addi- tives can be grouped into two broad categories: *activator adjuvants* include surfactants, wetting agents, stickers-spreaders, and penetrants; *special purpose* or utility modifiers such as emulsifiers, dispersants, stabilizing agents, coupling agents, co-solvents, com- patibility agents, buffering agents, antifoam agents, drift control agents, and nutritionals. Descriptions of the more common types of special purpose adjuvants follow. Table lists some common products sold for these purposes.

Selected trade names and manufacturers of special purpose adjuvants.

Trade name	Manufacturer
Compatibility agents	
Blendex VHC	Helena
Combine	Riverside/Terra
Complete	Cenex/Land O'Lakes
Latron AG-44M	Rohm and Haas
Drift inhibitors	
Intac Plus	Loveland Industries
Spray-Start	Kalo, Inc.
Sta-Put	Nalco Chemical Company
Strike Zone DC	Helena
Target NL	Agway
Windbreak	Riverside/Terra
Windcheck	Riverside/Terra
Anti-foaming agents	
DeFoamer	Riverside/Terra
Foam Buster	Helena
Buffers	
Ballast	Cenex/Land O'Lakes
Buffer P.S.	Helena
BS-500	Drexel
Combine	Riverside/Terra
Latron AG-44M	Rohm and Haas
Penetrator Plus	Helena

Special purpose adjuvants

Compatibility agents allow simultaneous application of two or more ingredients. They are most often used when herbicides are applied in liquid fertilizer solutions. Unless the pesticide label states that it can be mixed with liquid fertilizers, a compatibility agent should be included.

Buffering agents usually contain a phosphate salt or more recently citric acid, which maintains a slightly acid pH when added to alkaline waters. These are added to higher pH solutions to prevent alkaline hydrolysis (a chemical reaction) of some organicophosphate (OP) and carbamate insecticides. Some acidifying agents are also sold to enhance herbicide uptake and performance. However, there is little evidence to support the need for these acidifying agents for this purpose with most herbicides. Some buffering agents are also “water softening” agents that are used to reduce problems with hard water. In particular calcium and magnesium salts may interfere with the performance of certain pesticides. Ammonium sulfate (AMS) is sometimes added to reduce hard water problems. Examine the specific pesticide and water source to determine the need for a buffering agent.

Antifoam agents usually are added to suppress surface foam and minimize air entrapment that can cause pump and spray problems. Defoamers often contain silicone.

Drift control agents (thickeners) modify spray characteristics to reduce spray drift, usually by minimizing small droplet formation. Drift inhibitors are generally polyacrylamide or polyvinyl polymers to increase droplet size.

Activator adjuvants

Activator adjuvants are by far the most common type of additives used to enhance herbicide performance. Although some products are sold to alter pesticide-soil interactions, the emphasis of this discussion will be on foliar-applied materials. The primary use of activator adjuvants is with postemergence herbicide applications.

Before any foliar-applied herbicide can perform the desired biological function, it must be transferred from the leaf surface into the plant tissue. The above-ground portions of plants are covered by a continuous noncellular, nonliving membrane called cuticle (Figure 1). Cuticle is the first barrier that any herbicide must overcome to be effective. The plant cuticle is composed of water-repellent waxes and less water-repellent cutin and pectins which can provide pathways for more water-soluble pesticides. The structure of plant cuticle can be likened to a sponge where the matrix of the sponge corresponds to the cutin and the holes correspond to the embedded wax. The surface of the sponge is also covered with wax (epicuticular wax). Cuticle is extremely diverse and varies greatly be- tween different species of plants.

Waxes are the principal barrier restricting herbicide movement into plant foliage. The chemical or physical properties of the wax appear to be more important than thickness in restricting penetration. Surface wax high in hydrocarbons and other repellent molecules is less permeable to water and most herbicide sprays than cuticle membranes with lower amounts of water-restrictive waxes. For example, lambsquarters cuticle wax is known to be a strong barrier to the penetration of many herbicides. Lambsquarters cuticle is high in chemical substances called aldehydes, which may help prevent the passage of more water-soluble herbicides. Not only does cuticle composition vary between species, but also the age of the plant has been associated with differences in leaf wax chemistry over time.

The most common types of activator adjuvants employed are surfactants, oils, and salts. Activator adjuvants influence the physical and chemical properties of the spray solution, including surface tension, density, volatility, and solubility. These properties will in turn modify the spreading, wetting, retention, and penetration of the spray solution. It is important that the appropriate adjuvant is selected for a particular pesticide product. The type of adjuvant added to the spray tank can enhance or reduce the performance of the pesticide. The relative effectiveness of several adjuvants on herbicide performance is shown in Table. In both these trials, nonionic surfactant was less effective than other types of adjuvants, however, nonionic surfactant might be the more appropriate choice with other weeds or herbicides. The first step in choosing the correct additive for a spe- cific product is to read the pesticide label. The wrong adjuvant may increase the risk of poor performance and/or crop injury.

Effectiveness of adjuvants in selected weed trials at Penn State

	(% Control)	
Treatment [a]	**Wirestem Muhly [b]**	**Giant Foxtail [c]**
Accent + NIS	67	—
Accent + COC	73	—
Accent + MVOC	78	—
Pursuit + NIS	—	78
Pursuit + COC	—	95
Pursuit + DASH	—	94
Pursuit + DASH + UAN	—	99

[a] NIS = nonionic surfactant; COC = crop oil concentrate; MVOC + methylated vegetable oil concentrate; DASH = surfactant from BASF; UAN = 28 percent urea ammonium nitrate.

[b] Accent applied at 2/3 oz/A and averaged over two locations.

[c] Pursuit applied at 4 oz/A.

Surfactants

The primary purpose of a surfactant or “surface active agent” is to reduce the surface tension of the spray solution to allow more intimate contact between the spray droplet and the plant surface. Any substance that brings a pesticide into closer contact with the leaf surface has the potential to aid absorption. Surface tension is a measure of the surface energy in terms of force measured in dynes/cm. Water has a surface tension of 73 dynes/cm. Surfactants lower the surface tension of water to that of an oil, or solvent which spreads more readily than water on plant surfaces. Surfactants typically lower the surface tension of a solution to between 30 and 50 dynes/cm.

The interaction between surfactant, herbicide, and plant surface is far more complex than simply lowering the surface tension of the pesticide solution. Surfactant molecules may also alter the permeability of the cuticle. Surfactants form a bridge between unlike chemicals such as oil and water or water and the wax on a leaf surface. Although there are many different types of surfactants, in general, they are constructed of a long chain hydrocarbon group on one end that is considered lipophilic (fat loving) and a more hydrophilic (water loving) group of atoms on the other end. The structure of surfactants is often represented by a tadpole or polliwog type of arrangement such as seen in Figure 2. The zigzag tail represents the long chain hydrocarbon group that gives the molecule its lipophilic characteristics. The head of the polliwog contains more water-soluble (polar) groups that give the molecule its hydrophilic characteristics.

The influence of the surfactant on herbicide performance can be species specific because leaf wax composition varies. For some herbicides, surfactant preference is also herbicide dependent. For example, Roundup (glyphosate) is a more water-soluble herbicide that requires a more polar type of surfactant (such as the ethoxylated fatty amines) to improve activity. Highly lipophilic surfactants can actually decrease the performance of Roundup in comparison to no surfactant at all.

Surfactant molecules can be synthesized to achieve specific solubility characteristics often referred to as the hydrophilic-lipophilic balance (HLB). The capability of a surfactant to modify herbicide penetration is partially attributable to the HLB, with each herbicide-species interaction having an optimum HLB requirement for the surfactant employed. HLB numbers for surfactants are often given on technical information sheets for specific products. They range from 0 to 40 with most of them between 1 and 20. Low HLBs are very oil soluble, while higher HLBs prefer water.

Although there are hundreds of different surfactants, only a few are used in the pesticide adjuvant business. More than half the products used as stickers or wetter-spreaders use the same general surfactant type, alkyl-aryl-poly-oxy-ethylenate, or AAPOE. Exam- ples of AAPOE surfactants commonly used with herbicides are X-77 and Triton AG-98. The next most common type (about 25 percent) is very similar to AAPOE and is an alco- hol ethoxylate or alcohol-poly-oxy-ethylene (APOE). Examples of this type include Wex and Surfactant WK. Some surfactants may also contain free fatty acids or fatty acid esters or linear alkyl sulfonates (anionic) in the formulation that also contribute to the principal functioning agent. All surfactants contain inert ingredients that are considered nonfunctioning agents or formulation aids and can include isopropyl alcohol (IPA), propylene glycol (PG), and a poly siloxane foam retardant (Si). Although surfactants can vary considerably within these groups depending on molecular structure (e.g., number of carbon and hydrogen groups) and within a group whose principal function is the same, such as wetters-spreaders, it is not likely that differences between the same type of surfactant are great.

Surfactants are classified as *nonionic*, *anionic*, or *cationic*. Nonionic surfactants have no electrical charge and are generally compatible with most pesticides. Nonionic surfactants are most commonly used because of their universal fit. An anionic surfactant possesses a negatively charged functional group and is most often used with acids or salts. Anionic surfactants are more specialized and sometimes used as dispersants or compatibility agents. Cationic surfactants are used less frequently, but one group (ethoxylated fatty amines) has been frequently used with the herbicide Roundup.

The *organosilicone*-based materials are another group of surfactants more recently introduced. These surfactants are used in place of or in addition to more traditional nonionic surfactants. Proponents of these surfactants stress low surface tension, greater rain fastness, and possible stomatal penetration characteristics. Several silicone-based products are currently available for use with postemergence herbicides (Tables). Sur- factants and other adjuvants are either added to the spray tank on a per acre basis or a percent volume per volume (%v/v) concentration. For example, surfactants are usually applied at ½ to 2 pints per acre or at 0.25% v/v (i.e., 2 pt/100 gal) unless otherwise di- rected.

Selected trade names and manufacturers of nonionic surfactants

Trade name	Manufacturer
Activate Plus	Riverside/Terra
Activator 90	Loveland Industries
Adspray 80	Helena
Dash (surfactant + fatty acids)	BASF
Induce	Helena
Kinetic (organosilicone)	Helena
Latron AG-98	Rohm and Haas
Silkin (organosilicone)	Riverside/Terra
Silwet L-77 (organosilicone)	Loveland Industries
Spray Booster-S	Cenex/Land O'Lakes
Spret	Helena
Surf-Aid	Riverside/Terra
Surf-Ac 820	Drexel Chemical
Surf-Ac 910	Drexel Chemical
Triton AG-98	Rohm and Haas
X-77	Loveland Industries

Oils

Adjuvants that are primarily oil based are very popular with pesticide applicators. Crop oils are probably the oldest group within this category.

Crop oil is a misnomer because the material actually is from petroleum (paraffin or naphtha base, not vegetable derivative), a phytobland (nonphytotoxic), nonaromatic oil of 70 to 110 second viscosity (water = 1 and 30 w motor oil = 300). Crop oils are 95 to 98 percent oil with 1 to 2 percent surfactant/emulsifier. Crop oils are believed to promote the penetration of pesticide spray through waxy cuticle or the tough chitinous shell of insects.

Traditional crop oils are more commonly used in insect and disease control than with herbicides. Crop oils are typically used at 1 to 2 gallons per acre.

Crop oil concentrate contains 80 to 85 percent phytobland emulsifiable crop oil (petroleum based) plus 15 to 20 percent nonionic surfactant. The purpose of the surfactant in this mixture is to emulsify the oil in the spray solution and lower the surface tension of the overall spray solution. Crop oil concentrates attempt to provide the penetration characteristics of the oil, while capturing the surface tension reduction qualities of a surfactant. Crop oil concentrates are also important in helping solubilize less water-soluble herbicides such as Assure, Poast, Fusilade, Select, and atrazine on the leaf surface. Crop oil concentrates are used at 1 to 3 pints per acre at 1%v/v (1 gal/100 gal) unless otherwise directed.

Vegetable oil concentrates have performed less consistently than their petroleum-based counterparts. However, manufacturers are attempting to improve plant or vegetable-based oils by increasing their nonpolar or lipophilic characteristics. The most com- mon method has been through esterification of common seed oils such as methylated sunflower, soybean, cotton, and linseed oils. The methylated forms of these seed oil concentrates are comparable in performance to traditional (petroleum) crop oil concentrates so their importance has increased. In taking it one step further, organosilicone- based methylated vegetable oil concentrates are also available. These adjuvants boast the surface tension-reducing properties of silicone but have the advantages of a methylated vegetable oil concentrate. The more widely available oil-based additives are given in Table

Selected trade names and manufacturers of oil-based additives.

Trade name	Manufacturer
Crop oils	
Cenex Spray Oil	Cenex/Land O'Lakes
Dormant Oil	Riverside/Terra
Knock-Down Crop Oil	Cenex/Land O'Lakes
Crop oil concentrates	
Activate Oil Adjuvant	Drexel Chemical
Agri-Dex	Helena
CLASS 17% Concentrate	Cenex/Land O'Lakes
Crop Oil Concentrate	various
Herbimax	Loveland Industries
Peptoil	Drexel Chemical
Prime Oil	Riverside/Terra
Vegetable oil concentrates	
CLASS Destiny (methyl soybean)	Cenex/Land O'Lakes
Dyne-Amic (silicone methyl vegetable)	Helena
Meth Oil (methyl soybean)	Riverside/Terra
MSO	Loveland Industries

Prime Oil II (vegetable)	Riverside/Terra
Sun-It II/Scoil (methyl vegetable)	Agsco
Vegetable Oil Concentrate (vegetable)	Helena
Vegetoil	Drexel Chemical

Nitrogen fertilizer

Within the last 15 years, nitrogen fertilizers have been more frequently added to the spray solution as an adjuvant to increase herbicide activity. Ammonium salts (NH_4^+) appear to be the active component of these fertilizer solutions and have improved the performance consistency on some weeds. It is still unclear how ammonium salts improve herbicide performance. Herbicides that appear to benefit from the addition of ammonium are the relatively polar, weak acid herbicides such as Basagran, the sulfonylureas (Accent, Beacon, Classic, and Pinnacle, etc.), and the imidazolinones (Pursuit and Raptor). Nitrogen fertilizers may replace surfactant or crop oil concentrate with some of the contact-type herbicides, but are usually added in addition to surfactant or crop oil concentrate with systemic products.

Velvetleaf and some grassy annual weeds in particular have been responsive to the addition of nitrogen fertilizer in the spray mix. In general, velvetleaf control has improved by as much as 10 to 25 percent by the addition of an ammonium-based fluid fertilizer (28, 30, or 32 percent UAN, 10-34-0, or 21-0-0), compared to crop oil concentrate or surfactant. Common rates are 2 to 4 quart/acre of 28, 30, or 32 percent UAN, I quart/acre of 10-34-0, or 17 pounds/100 gallons dry ammonium sulfate. Some broadleaves and grasses show little or no response with the inclusion of ammonium fertilizer solutions.

Ammonium-based fertilizers and, in particular, ammonium sulfate (AMS) are also being promoted to reduce potential antagonism with hard water or antagonism with other pesticides. Both hard water antagonism and pesticide antagonism can occur with some herbicides. Roundup (glyphosate) is one product that specifically recommends on its label the addition of ammonium sulfate (or a higher rate of Roundup) for hard water, cool air temperatures, or drought conditions. Examine the specific pesticide label, water source, and environmental conditions to determine the need for AMS or other adjuvants.

Adjuvant selection

Adjuvant selection should be based on several factors including what the pesticide calls for, what the adjuvant claims to be, cost of the adjuvant, and what is available in your area. The primary source in deciding whether an adjuvant is necessary and the type of adjuvant used should come from the pesticide label. The following are some general guidelines to consider when given a choice of adjuvants.

- If both oil concentrate (crop or vegetable oil) and nonionic surfactant are listed, then use nonionic surfactant under normal weather conditions when weeds are small and well within label guidelines. Use oil concentrate if weeds are stressed due to dry weather or with more mature weeds.

- If labeled, include oil concentrate for control of grasses.
- Include nitrogen fertilizer only if it is recommended on the herbicide label.
- If the potential for crop injury is great, then use nonionic surfactant instead of oil concentrate.
- To improve crop safety, do not include oil concentrates with plant growth regulator-type herbicides (i.e., dicamba, 2,4-D, etc.)

Manufacturers of most products and particularly the newer materials have invested time and money in adjuvant research. Some labels are very specific in their recommenda- tion of adjuvants. For example, the Pursuit label for postemergence use in soybean states "use a nonionic surfactant containing at least 80% active ingredients and apply at 1 qt/100 gal *or* a petroleum or vegetable seed-based oil concentrate at 1.5 to 2 pt/acre *and* a nitrogen-based fertilizer such as 28% N, 32% N, or 10-34-0 at 1 to 2 qt/A." Other product labels such as Buctril on corn are not as specific and simply state that "Buctril can be ap- plied in combination with sprayable liquid fertilizer or spray additives such as surfactants or crop oil concentrate." When pesticide labels are not specific enough, other important sources include university crop management guides (i.e., *Penn State Field Crop Weed Control Guide* or *The Agronomy Guide)* and industry-based publications.

Next select an appropriate product within the required group or type of adjuvants recommended. This can be confusing since some products contain several different types of adjuvants. The claims made for an adjuvant product on the label and in the active ingredient statement can be helpful in selecting the best adjuvant for your needs. In particular, pay close attention to the percent active vs. inert ingredients. For example, Activate Plus from Riverside/Terra Corp. is a nonionic spreader/activator that is typical of nonionic surfactants recommended for use with postemergence herbicides. The active ingredient portion of Activate Plus includes AAPOE, free fatty acids, and isopropyl alcohol.

These three ingredients make up 90 percent of the product with the remaining 10 percent being inert ingredients. Agri-Dex from Helena claims to be a nonionic spray adjuvant or more specifically a crop oil concentrate that is recommended for use with pesticides requiring an oil concentrate adjuvant. The active ingredients make up 99 percent of the formulation and include paraffin-based petroleum (crop oil), fatty acid esters, and AAPOE or APOE, which all contribute to the active portion of the adjuvant. Loveland Industries manufactures Chem-Trol that is identified as a spray additive for deposition and drift retardation. The active ingredient in Chem-Trol is a polyvinyl polymer at 1 percent with 99 percent inert ingredients. This product is not recommended to enhance pesticide activity, but rather to reduce pesticide drift. Be sure to thoroughly read the label.

The active ingredient portion of the label can also be helpful in comparing costs. If two products have the same or similar active ingredients yet slightly different concentra- tions, you can calculate the cost of each product on an active ingredient (ai) basis. For example, two adjuvant products both cost $11.00 per gallon. Product A has 90 percent active ingredient, while Product B contains 80 percent. Both products serve the same principal function. Product A's actual cost is $12.22 per gallon of active ingredient (11.00/0.90), while Product B's is $13.75 (11.00/0.80). Which would you choose? This may become even more important as new higher-cost adjuvants enter the marketplace.

Summary

The type of adjuvant added to the spray tank can enhance or reduce the performance of the pesticide. Both herbicide and species influence the appropriateness of the adjuvant. Although a number of different kinds of activator adjuvants are on the market, their primary purpose is to reduce the surface tension, improve the wetting action, and increase the penetration of the pesticide. To choose the correct additive for a specific product, first read the pesticide label. An appropriate adjuvant assures maximum performance and crop safety. The wrong adjuvant increases the risk of poor performance and crop injury.

Bio-herbicide

The origins of biological weed control

In ancient times, the Chinese discovered that increasing ant populations in their citrus groves helped decrease destructive populations of large boring beetles and caterpillars. That use of a natural enemy to control a pest marked the birth of biological control

Biological control research and implementation is even more relevant today. Foreign and native organisms that attack weeds are being evaluated for use as biological control agents. As a weed management method, biological control offers an environmentally friendly approach that complements conventional methods. It helps meet the need for new weed management strategies since some weeds have become resistant to certain herbicides. Biological control agents target specific weeds. Moreover, this technology is safe for applicators and consumers

The problem with weeds

Weeds can be defined as plants growing out of place. For example, waterhyacinth is beautiful in floating gardens but can rapidly clog waterways, making navigation impossible (cover, center-left photo). Similarly, morningglory is beautiful in the garden, but when it entwines corn stalks, it can destroy a farmer's crop.

Weeds degrade native ecosystems.

Invasive, noxious weeds such as leafy spurge and yellow starthistle infest millions of acres of rangeland and wilderness areas in the northern plains and are estimated to cost tens of millions of dollars annually in lost grazing and associated economic effects. For example, leafy spurge and yellow starthistle spread and form dense stands competing with native plants, reducing plant diversity, and degrading wildlife habitats.

Weeds foul waterways

Purple loosestrife has run rampant in U.S. waterways and natural wetland ecosystems, choking out cattails and other native aquatic plants that provide food and shelter for fish, mammals, birds, and reptiles. Many believe that purple loosestrife seeds arrived in the United States during the early 1800's in soil used as ship ballast

Weeds lower property values

Knowledgeable people avoid buying land infested with invasive weeds. Much time and money will probably be required to convert weed-infested fields to more productive or aesthetically pleasing land.

Many troublesome weeds in the United States are natives of other countries. These weeds were brought to North America accidentally or deliberately and arrived without the living organisms that infect or feed upon them. Without their natural enemies, these exotic plant species rapidly populate new ecosystems that are favorable for their growth.

There are many methods of destroying weeds. We have tried burning them, pulling them out or chopping them down, and treating them with herbicides - all with mixed results. A combination of control methods is generally required to best manage these nuisance plants. Biological control holds much promise for long-term, economical, and environmentally sensitive weed management.

What is biological control of weeds?

Biological weed control involves using living organisms, such as insects, nematodes, bacteria, or fungi, to reduce weed populations. In nature, plants are controlled biologically by naturally occurring organisms. Plants become pests-and are labeled "weeds" - when they run rampant because their natural enemies become ineffective or are nonexistent. The natural cycle may be interrupted when a plant is introduced into a new environment, or when humans disrupt the ecological system. When we purposefully introduce biological control agents, we are attempting to restore or enhance nature's systems.

Mode of Work

Roots provide plants with water and nutrients. Some biological control agents attach to roots and thereby stunt plant growth. Some bacteria live on root surfaces and release toxins that stunt root growth. Many fungi infect roots and disrupt the water transport system, which reduces leaf growth. Beneficial insects and nematodes feed directly on the weed roots causing injury which allows bacteria and fungi to penetrate.

Plant leaves capture energy from the sun and store it as sugar. Insects that feed on leaves reduce the leaf surface available for energy capture. Fungi and bacteria that infect leaves reduce the ability of the leaf to make sugars. In either case, there is less energy available for weed growth. Whether through damage on roots or leaves, severe infestations of biological control agents can actually kill weeds, reducing their adverse effects on desirable plants.

Many weed species survive from year to year by producing seeds. Fungi or insects that attack seeds can reduce the number of weed seeds stored in the soil, which in turn can reduce the size of future weed populations. This lowers the effort needed to control the remaining emerging weeds.

Some bacteria and fungi applied as biological control agents do not survive from year to year. These organisms must be applied on an annual basis. This technique is called the "**bioherbicide**" strategy. With this tactic, biological agents are used a in manner similar to chemical herbicides.

Weeds introduced from foreign countries often require a different strategy. Insects and pathogens are collected in the area of origin and evaluated for release in North America. Insect agents often require a number of years to become fully effective. Their growth is often hindered by adverse climatic conditions. Long-term monitoring is needed to determine their effectiveness. The release of biological control organisms in this manner is termed the "**classical**" approach to biological control. Fungi that naturally spread and infect weeds can also be used in a classical biological control strategy.

Biological control is worth the effort

It is well demonstrated that weeds can be controlled biologically. Deleterious rhizobacteria have been used to stunt weed growth in wheat fields in the Pacific Northwest. A rust fungus has been used to eliminate rush skelet on weed from thousands of acres of rangeland in the West. A complex of introduced insects has also cleared alligatorweed from waterways, rice fields and lakes in the South.

The cost of developing and conducting a biological control program varies with the target weed and the strategy selected. On average, a biological control program will cost about $4 million. But every dollar spent in development returns at least $50 in benefit.

Biological control of weeds will not eliminate the need to use chemical herbicides. Both of these tools need to be integrated with cultural practices, such as tillage and crop rotation, in the battle against weeds. By using Integrated Weed Management, the development of weeds that are resistant to biological or chemical agents can be slowed.

Why isn't everyone using biological control

Despite the fact that scientists have demonstrated that biologically based herbicides can be effective, there are currently (2000) only two products (DeVine® and COLLEGO®) being sold in the U.S. and Canada. There has been little incentive for companies to become involved in the development of these products and it is often difficult to protect the use of these agents with patents.

Although some insects have been successfully introduced into North America to control exotic weeds, the process is very time consuming. A single agent is rarely able to completely suppress a target weed and multiple agents require additional time for research and development.

The Animal and Plant Health Inspection Service (APHIS) regulates the introduction of biological control agents for weeds. There are very stringent requirements to insure that non-target plants are not damaged in an attempt to control weeds. It can take 20 scientist-years to take a single project from initial exploration through testing and introduction, to establishment and monitoring.

Biological control of weeds needs your support

If the continued development of biological weed control is important to you, the time to act is now. Ask your Senators and Representatives to support funding for research and development of both classical and bioherbicide agents. Encourage them to require government agencies to implement sensible, economical biological control regulations that facilitate, rather than impede, the research and development of weed biocontrol agents.

With public support, solutions to weed control problems can be achieved. But we should all understand also that how soon biological solutions to weed control are available is a function of the amount of financial support that the research receives. When used in an integrated approach, property owners and farmers will benefit from this method of weed management.

Who's responsible?

Federal government agencies are responsible for:

- Identifying those weeds that threaten native habitats, agriculture, or the economy, and are potential candidates for biological control;
- Funding research efforts;
- Conducting national and international research;
- Checking documentation and research results before allowing potential biological control agents into the country;
- Keeping records of the location and effects of biological control agents after their release;
- Publishing results and communicating biological control results to the public;
- Implementing the biological control of weeds on federal lands as part of an Integrated Pest Management program mandated by Congress;
- Writing and implementing effective biological control regulations

State Departments of Agriculture are responsible for:

- Identify target weeds for biological control research;
- Keeping records of releases of biological control agents within the state;
- Coordinating biological control efforts within the state.

Universities and other research organizations are responsible for:

- Identifying weeds for biological control research;

- Conducting overseas and domestic research, sometimes in partnership with federal agencies;
- Distributing and monitoring biological control agents;
- Publishing results;
- Educating the public about biological control processes

Professional organizations are responsible for:

- Supporting biological control research;
- Publishing research results;
- Encouraging and coordinating interagency research projects;
- Educating the public about research progress and needs.

Private industry is responsible for:

- Funding facets of biological control research that may result in commercial products;
- Helping to educate the public about proper use of biological control agents;
- Redistributing commercial biological control agents.

Farmers/Growers are responsible for:

- Helping with field assessments;
- Integrating Biological control agents into pest management and production practices;
- Assisting on cost effectiveness estimates

Herbicide Combinations or Herbicide Mixtures

Herbicide combination or mixtures are used for effective and economical weed control. In this method two or more herbicides are used. Herbicide combination after certain advantages like broad spectrum of herbicidal action. Synergistic or active effects, prevention of detoxication of one of the herbicide in the mixture, reduction of the doses of the herbicides etc.

There are two Types of Herbicide Mixtures:

1) The tank mixtures made with desired herbicides and rates just before application.
2) The concocted herbicide mixtures formulated by the companies at the time of manufacturing.

Herbicides Mixtures and Their Effect on the Weed Control:

Herbicide Mixture	**Trade Name**	**Crop**	**Weeds Killed**
MSMA + Barban		Wheat	Wild Oat and Green foxtail millet and dicot weeds
Atrazine + Metalachlor		Maize	Monocot and Dicot weeds
Dicamba + MCPA	Dialemt – D	Wheat	Most of the weeds
2, 4-D amine + Dicamba	Dialem	Wheat	Effective on weeds resistant to 2, 4-D
Mecoprop + Dicamba	Diaprem	Wheat	Effective on weeds resistant to 2, 4-D

Herbicide Application Techniques

Herbicides are applied as pre-planting (before planting the crop); pre-emergence (after planting, but before emergence of the crop); and post-emergence (after crop emergence) depending on the crop and weed situation in the field. Most of the herbicides are applied in liquid form, where formulation is mixed with water. Obviously, different types of sprayer are available for the application of herbicides. But a very few number of granular formulation is also available in Indian market. These are generally applied in the field by hand.

Herbicide applicator: Some popular types of herbicide application equipment available are: knapsack sprayer, compression knapsack sprayer, motorized knapsack sprayer, tractor mounted sprayer, handheld granule applicator etc. The most ideal for spraying herbicide is the lever operated knapsack sprayer (Fig.). With this sprayer it is possible to spray 0.5 ha with the single nozzle in 8 hours in a day. The nozzle helps to control the rate, consistency, thoroughness and safety of herbicide application. It carries out four basic functions: atomises liquid to droplets; disperses the droplets in a specific pattern; meters liquid at a certain low rate; and provides hydraulic momentum. The nozzle tip, one of the most important parts of spraying system, guides the spraying pattern. Depending on the nature of tip various types of nozzle has been developed and commercialized. In herbicide application, flood jet and flat fan nozzles are useful as the attachment of knapsack sprayer (Fig.). When it is desired to spray with more than one nozzle with the help of a spray rig or spray boom, care should be taken in mounting to shun any overlapping or gapping.

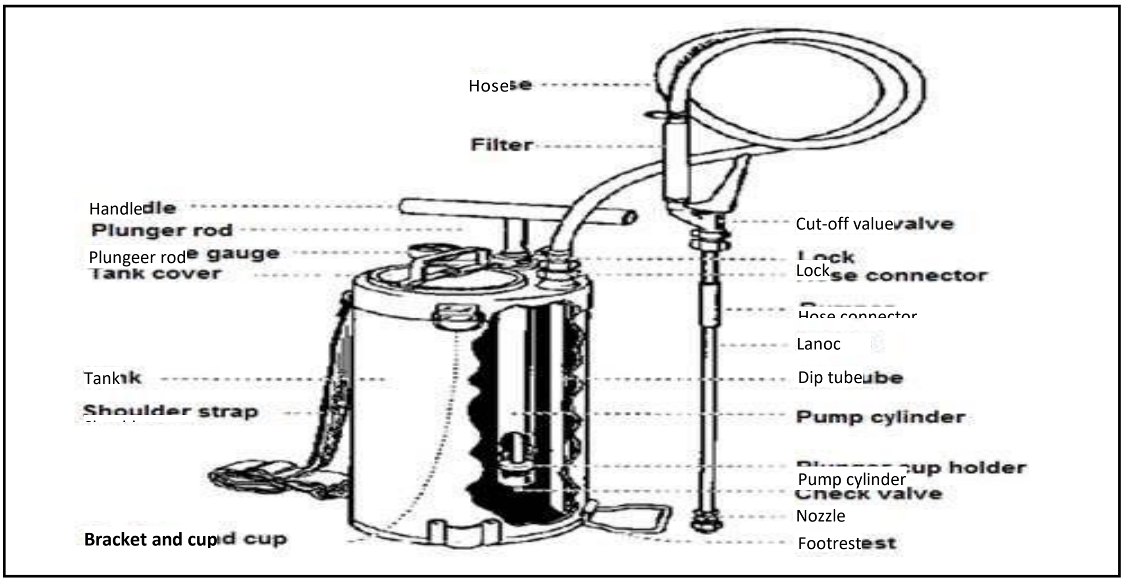


Fig. Different parts of knapsack sprayer

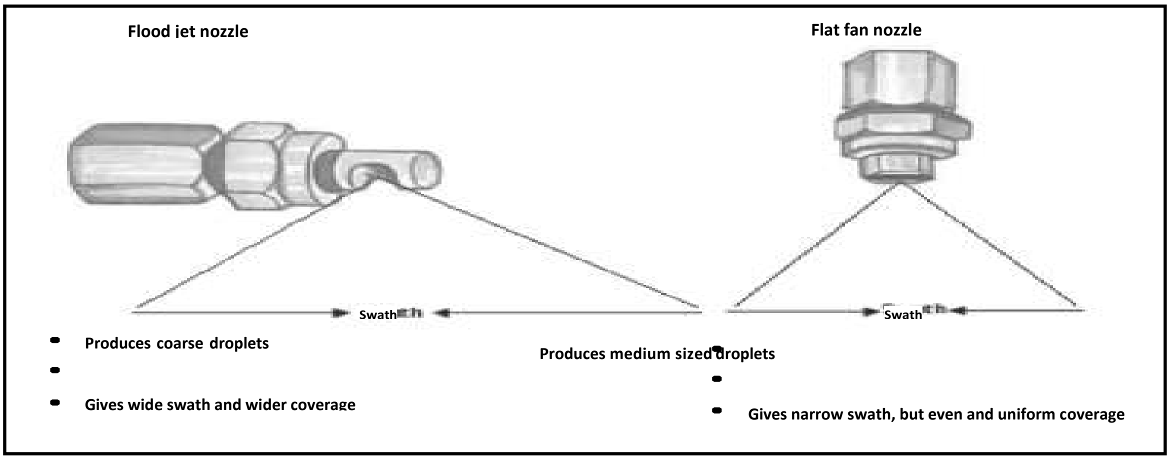


Fig. Comparative study of flood jet nozzle and flat fan nozzle

Calibration of the sprayer :

- Mark an area having a width equal to the swath width
- Keep the sprayer on a levelled ground and fill the water to a marked level
- Cary out spraying in the marked area at a normal speed
- Avoid skipping or overlapping
- Refill the sprayer to the original level marked earlier
- The quantity refilled is the quantity required to spray the marked area.
- Work out the volume rate/ ha

Example:

Marked area: 20 square meters
Quantity of water used: 1 L
Volume rate = (1X10,000)/ 20 = 500 L/ ha

Calculation of herbicide requirement: The amount of commercial formulation of the herbicide required can be calculated by the following formula:

Commercial product (kg/ ha) =

Maintenance of the equipments:

The sprayer should be well maintained during the spraying season. It is very important to clean both inside and outside of sprayers after each day's work, even if the same chemical is being used the next day. Sprayer should be lubricated thoroughly and regularly before starting the work. All parts should be inspected regularly and damaged parts should be replaced immediately. The nozzle should be checked, and if required, it should be replaced.

Safety related to spraying:

Before spraying

1. Identify the weed and its extent of damage. If it crosses economic injury level, use the recommended herbicide.
2. Check the spraying equipment and accessories.
3. All components should be clean. Replace worn out parts such as 'O'-ring, seal, gasket, nozzle tip, hose clamps and valves.Test the sprayer with water. Check the nozzle spray pattern and discharge rate.

4. Calibrate the sprayer. Set spraying speed and nozzle swath by adjusting the spray height and nozzle spacing.
5. Herbicide should be kept in a dry and locked store.

During spraying

1. Take herbicide sufficient for the day's need, not more.
2. Herbicide formulation should be mixed with water in the correct quantities as mentioned in the instruction.
3. Wear appropriate clothing, such as cap, goggles, face-mask, apron, hand gloves, footwear.
4. Do not spray during high wind and rain.
5. Never eat, drink and smoke during spraying.
6. Spray correctly by operating sprayer at the right speed and pressure.
7. Never try to clean the clogged nozzle by blowing with your mouth.
8. Do not allow children and animals to be nearby during mixing and spraying.

After spraying

1. Unused herbicides in the spray tank should be disposed of in pits dug in the wasteland.
2. Clean the equipment and other accessories with water thoroughly. Do not clean it in a pond or river.
3. After use, oil the sprayer.
4. Crush and bury the empty herbicide containers in a land-filled dump.
5. Remove and wash protective clothing and footwear.
6. Wash yourself well.
7. Keep a proper record of herbicide uses.

Cost of herbicide application

The cost of herbicide application depends on the type and stage of crops and weed status in crop. For the weed management in wheat, a number of herbicides and ready mix combinations of herbicides is available in the market. If the field is infested with only broad leaf weeds, the use of metsulfuron is advisable because it is the cheapest herbicide among all available in our market. If crop is infested with oat and broadleaf weeds the ready mix combination of clodinafop + metsulfuron is yielding better results. The field infested with isoproturon-resistant *Phalaris minor* and some broad leaf weeds can be managed by a ready mix combination of mesosulfuron and iodosulfuron or sulfosulfuron and metsulfuron.

Butachlor was vastly used for managing weeds in rice in the recent past. It is still popular due to its low application cost, only ` 500 per hectare excluding the labor cost (Table 7.1). With the introduction of new molecules like bispyribac, cyhalofop, fenoxaprop etc., the options for post- emergence application of herbicide in rice became wide open. The weed management in direct- seeded rice is becoming easy now and it is more economic in comparison to manual weeding, which ranges from ` 4900 (Meghalaya) to ` 9660 (Gujarat) per ha, calculated on the basis of the minimum wages of labours.

For many years, there were not many option of chemical weed control in pulses as only pre- emergence herbicides, arachlor etc. were available pendimethalin. Now with the introduction of new low-dose high potency chemicals like image thapyr, quizalofop, clodinafop etc., which can be used safely in black gram, greengram and pigeon pea more economical weed management is possible in pulse crops.

Compatibility of herbicides with other agro chemicalsand their application

Simultaneous or sequential application of herbicides, insecticides, fungicides, antidotes, fertilizers etc., is followed in a single cropping season. These chemicals may undergo a change in physical and chemical characters, which could lead to enhancement or reduction in the efficacy of one or more compounds. The interaction effects were seen much later in the growing season or in the next season due to build-up of persistent chemicals or their residues in the soil. Knowledge on the interactions of various chemicals can be helpful in the formulation and adoption of a sound and effective plant protection programme. It can also help to exploit the synergistic and antagonistic interactions between various pesticides for an effective eradication of weed and other pest problems. When two or more chemicals accumulate in the plant, they may interact and bring out responses. These responses are classified as additive, synergistic, antagonistic, independent and enhancement effects.

i) Additive effect: It is the total effect of a combination, which is equal to the sum of the effects of the components taken independently.

ii) Synergistic effect: The total effect of a combination is greater or more prolonged than the sum of the effects of the two taken independently e.g. The mixture of 2,4-D and Chlorpropham is synergistic on monocot species generally resistant to 2,4-D. Similarly, low rates of 2,4-D and Picloram have synergistic response on Convolvulus arvensis. Atrazine and Alachlor combination, which shows synergism is widely used for an effective control in corn.

iii) Antagonistic effect: The total effect of a combination is smaller than the effect of the most active component applied alone e.g. Combination of EPTC with 2,4-D, 2,4,5-T or dicamba have antagonistic responses in sorghum and giant foxtail. Similarly, chlorpropham and 2,4-D have antagonism. When simazine or atrazine is added to glyphosate solution and sprayed the glyphosate activity is reduced. This is due to the physical binding within the spray solution rather than from biological interactions within the plant.

iv) Independent effect: The total effect of a combination is equal to the effect of the most active component applied alone.

v) Enhancement effect: The effect of a herbicide and non-toxic adjuvant applied in combination on a plant is said to have an enhancement effect if the response is greater than that obtained when the herbicide is used at the same rates without the adjuvant e.g. Mixing Ammonium sulphate with Glyphosate.

Herbicide-moisture interaction

Soil applied herbicides fail when there is a dry spell of 10-15 days after their application. Pre-emergence herbicides may be lost by photo-decomposition, volatilization and wind blowing while some amount of water is desirable to activate the soil applied herbicides, excess of it may leach the herbicide to the crop seed and root zone. This may injure the crops and on other side, results in poor weed control. Heavy showers may wash down herbicides from the foliage. Continuous wet weather may induce herbicide injury in certain crops by turning them highly succulent e.g. Maize plants are normally tolerant to Atrazine but they become susceptible in wet weather, particularly when air temperature is low. Extra succulence has been found to increase atrazine absorption and low temperature decreases its metabolism inside the plants. Quality of water used may also determine herbicide action. Dusty water reduces action of paraquat. Calcium chloride rich water reduces glyphoste phytotoxicity.

Herbicide-insecticide interaction

These chemicals are usually not harmful at recommended rates. The tolerance of plants to a herbicide may be altered in the presence of an insecticide and vice versa. The phyto-toxicity of monuron and diuron on cotton and oats is increased when applied with phorate. Phorate interacts antagonistically with trifluralin to increase cotton yield, by stimulating secondary roots in the zone of pesticide incorporation.

Propanil interacts with certain carbamate and phosphate insecticides used as seed treatments on rice. But chlorinated hydrocarbon insecticides as seed treatment have not interacted with propanil. When propanil is applied at intervals between 7 and 56 days after carbofuron treatment, it results in greater injury to rice vegetatively.

Herbicide-pathogens / fungicides interaction

Herbicides interact with fungicides also. In sterilized soil, chloroxuron is not causing any apparent injury to pea plants, while in the presence of *Rhizoctonia solani i*n unsterilized soil it causes injury. Oxadiazon reduces the incidence of stem rot caused by the soil borne pathogen *Sclerotium rolfsii* L. in groundnut. Diuron and triazine which inhibit photosynthesis may make the plants more susceptible to tobacco mosaic virus. On the other hand, diuron may decrease the incidence of root rot in wheat.

Herbicide-fertilizer interaction

Herbicides have been found to interact with fertilizers in fields e.g., fast growing weeds that are getting ample nitrogen show great susceptibility to 2,4-D, glyphosate than slow growing weeds on poor fertility lands. The activity of glyphosate is increased when ammonium sulphate is tank mixed. Nitrogen invigorate (put life and energy in to) the meristamatic activity in crops so much that they susceptible to herbicides. High rates of atrazine are more toxic to maize and sorghum when applied with high rates of phosphorus.

Herbicide-microbes interaction

Microorganisms play a major role in the persistence behaviour of herbicides in the soil. The soil microorganisms have the capacity to detoxify and inactivate the herbicides present in the soil. Some groups of herbicides more easily degrade through microbes than others. The difference lies in the molecular configuration of the herbicide. The microorganisms involved in herbicide degradation include bacteria, fungi, algae, moulds etc. Of these, bacteria predominates and include the members of the genera *Agrobacterium, Arthrobacter, Achromobacterium. Bacillus, Pseudomonas, Streptomyces, Flavobacterium, Rhizobium* etc. The fungi include those of the genera *Fusarium, Penicillium* etc.

Mixing of herbicides

1. Be sure there is sufficient agitation in the sprayer tank to prevent settling of wettable powders, dry flowables, or flowables.} Recalibrate sprayers frequently and adjust them for increased output resulting from normal nozzle wear } Slight increases in rates could result in crop injury or leave residues that might injure succeeding crops. } Mix only the recommended amount of herbicide. } Be aware that improper sprayer calibration, calculation errors, or use of the wrong chemicals can cause herbicide injury to the crop. }Mixing Herbicides before Application- Warning
2. Add, mix, and disperse dry formulations (wettable powders, dry flowables, or water-dispersible granules).¬ Fill the sprayer tank at least halfway. ¬ Calculate the amount of herbicide needed. ¬ Read the label ¬STEPS WHEN MIXING
3. Pre-mixing the following: Wettable powders (WP). Dry flowable (DF) and water-dispersing granules (WDG), Liquid flowables (Ratio=1:2)} 5. Surfactants } 4. Emulsifiable concentrates (EC) } 3. Liquid and Soluble products } 2. Agitate then add adjuvants such as anti-foaming compounds, buffers } 1. Wettable Powders (WP) then Flowables (F, DF) } Herbicide labels usually provide directions for mixing different materials, often describing the sequence of mixing. Whenever a label provides such directions, you should follow them. In general, follow the W-A-L-E-S plan when adding herbicides to a tank mix. }Mixing Order.
4. Mix no more than one soluble or emulsifiable chemical with any insoluble products such as wettable powders or flowables.¬ Do not mix iron sulphate with phenoxy herbicides. Iron sulphate is incompatible with amine formulations of some phenoxy herbicides and can cause a precipitate to form, clogging spray equipment. ¬ Make a test application to expose any phytotoxicity or antagonism before you make a large-scale application. If you overlap a few strips, this also can show you how much of a margin of safety you have. Wait a few days for symptoms to become visible. ¬ Test pH Many incompatibilities result from excessively alkaline (sometimes acidic) pH in the tank. The addition of buffering adjuvants can help. ¬ Caution: Never pour concentrated herbicides into a empty tank. Never allow a sprayer containing mixed chemicals to stand without agitation, as heavy wettable powders may clog nozzles or settle into corners of the sprayer tank ¬ Add the remainder of water and agitate. ¬MIXING STEPS-Contd.

5.Do not mix granular formulations with liquids MIXING STEPS-Contd.} Often EC formulation and WP formulations result in phytotoxicity. This is often due to the solvents, carriers, emulsifiers. } Apply sprays soon after mixing. Mixes that sit for several hours or longer are prone to degrade, especially if the pH is alkaline. ¬ Avoid mixing strongly acid materials with strongly alkaline materials ¬ Mix no more than one soluble or emulsifiable chemical with any insoluble products such as wettable powders or flowables. ¬

6.Excessive runoff Effects of mixing incompatible herbicides may include¬ Excessive residues ¬ Plant phytotoxicity, stunting or reducing seed germination ¬ Precipitate in the tank, clogging screens and nozzles in the sprayer. ¬ Reduced effectiveness of one or both compounds ¬

7. Keep containers below eye level when opening and po¬ Be aware of all mixing requirements and procedures indicated on the product labels. ¬ When handling herbicides on- site, always follow PPE precautions and keep in mind the importanceof safety before making the mixtures. ¬Applicator Safety Tips When Mixing Products Be aware of wind direction before pouring to minimize exposure downwind.¬ Keep fill hoses above water level in the spray tank to prevent back-siphoning. ¬uring

Herbicide Interactions

Simultaneous or sequential application of herbicides, insecticides, fungicides, antidotes, fertilizers etc., is followed in a single cropping season. These chemicals may undergo a change in physical and chemical characters, which could lead to enhancement or reduction in the efficacy of one or more compounds. The interaction effects were seen much later in the growing season or in the next season due to build up of persistent chemicals or their residues in the soil. Knowledge on the interactions of various chemicals can be helpful in the formulation and adoption of a sound and effective plant protection programme. It can also help to exploit the synergistic and antagonistic interactions between various pesticides for an effective eradication of weed and other pest problems.

When two or more chemicals accumulate in the plant, they may interact and bring out responses. These responses are classified as additive, synergistic, antagonistic, independent and enhancement effects.

i. **Additive effect:** It is the total effect of a combination, which is equal to the sum of the effects of the components taken independently.
ii. **Synergistic effect:** The total effect of a combination is greater or more prolonged than the sum of the effects of the two taken independently. The mixture of 2,4-D and chlorpropham is synergistic on monocot species generally resistant to 2,4-D. Similarly, low rates of 2,4-D and picloram have synergistic response on *Convolvulus arvensis.* Atrazine and alachlor combination, which shows synergism is widely used for an effective control in corn. Other examples are 2,4-D+ Dicamba; 2,4-D + Atrazine, and Amitrole + Ammonium thiocynate.
iii. **Antagonistic effect:** The total effect of a combination is smaller than the effect of the most active component applied alone. Eg. Combination of EPTC with 2,4-D, 2,4,5-T or dicamba have antagonistic responses in sorghum and giant foxtail. Similarly, chlorpropham and 2,4-D have antagonism. When simazine or atrazine is added to glyphosate solution and sprayed the glyphosate activity is reduced. This is due to the physical binding within the spray solution rather than from biological interactions within the plant. EPTC with 2,4-D or Dicamba in sorghum; Simazine or Atrazine with glyphosate reduces the activity of glyphosate.
iv. **Independent effect:** The total effect of a combination is equal to the effect of the most active component applied alone.
v. **Enhancement effect:** The effect of a herbicide and non-toxic adjuvant applied in combination on a plant is said to have an enhancement effect if the response is greater than that obtained when the herbicide is used at the same rates without the adjuvant. Eg. Mixing Ammonium sulphate with glyphosate.

Herbicides applied in combination either preplant incorporated or preemergence generally increase the spectrum of weed control or the length of residual weed control. For example, pendimethalin is often applied in combination with alachlor, dimethenamid-*P*, metolachlor, or *S*-metolachlor to improve early season weed control. Alachlor, dimethenamid-*P*, metolachlor, or *S*-metolachlor can be applied with diclosulam, flumioxazin, or imazethapyr preemergence to enhance weed control with a single application.

Combinations of preplant incorporated or preemergence herbicides currently registered for use in peanut have not been shown to increase peanut injury over either herbicide component applied alone. However, several herbicides that are no longer registered for peanut increased peanut injury when co-applied as compared to the herbicides applied alone.

In reduced tillage systems, herbicides are needed to control winter weeds and summer annual weeds that have emerged prior to planting peanut. These herbicide applications include glyphosate, paraquat, or 2,4-D alone or in combinations with other herbicides. Combinations of glyphosate and 2,4-D broaden the spectrum of weed control compared with each herbicide applied alone (Flint and Barrett, 1989a). However, in some instances, 2,4-D can negatively affect efficacy of glyphosate, but this interaction is typically noted only on grass weeds (Flint and Barrett, 1989b). Efficacy of paraquat is generally not negatively affected by 2,4-DB (Wehtje *et al*., 1992a). Glyphosate and paraquat can also be applied with herbicides that provide residual weed control. This approach is designed to control emerged weeds and provide residual weed control prior to and following planting.

Paraquat is often applied at peanut emergence or up to 28 days after peanut emergence. Other non-residual herbicides such as bentazon or acifluorfen plus bentazon as well as residual herbicides such as alachlor, iclosulam, dimethenamid-*P*, imazethapyr, metolachlor, or *S*-metolachlor are applied postemergence to broaden the spectrum of control. Injury associated with paraquat can be reduced by coapplication with bentazon. However, the chloroacetamide herbicides alachlor, dimethenamid-*P*, metolachor, or *S*-metolachlor applied with paraquat can increase peanut injury. Diclosulam and imazethapyr did not affect injury potential from paraquat. Weed control with these herbicide combinations generally increases depending on the weed species and size of the weed. For example, bentazon and imazethapyr co-applied can increase control of emerged common cocklebur and yellow nutsedge, while control of annual grasses by paraquat can be reduced when paraquat is co-applied with bentazon. Residual control by chloroacetamide herbicides, diclosulam, and imazethapyr was not affected by paraquat applied alone or with bentazon.

Co-application of postemergence herbicides with efficacy against dicotyledonous weeds and sedges generally increases control of weeds or broadens the spectrum of control compared with components of the mixture applied alone. In contrast, efficacy of clethodim and sethoxydim, often referred to as graminicides, can be reduced when applied in mixture with herbicides that control dicotyledonous weeds and sedges. The interaction of bentazon and sethoxydim is one of the most notable examples of reduced graminicide efficacy caused by a herbicide that controls dicotyledonous plants and sedges. Annual and perennial grass control by sethoxydim is reduced by bentazon through reduced absorption of sethoxydim into grasses. The mechanism of reduced control is associated with physical interactions of the herbicides in the spray solution prior to reaching the target weed. Acifluorfen and imazethapyr also can reduce efficacy of clethodim and sethoxydim. In contrast to reduced grass control when these herbicides are co-applied, control of dicotyledonous plants and sedges is not reduced by clethodim and sethoxydim. Efficacy of clethodim can also be reduced by acifluorfen, acifluorfen plus bentazon, bentazon, imazethapyr, imazapic, lactofen, and 2,4-DB. The magnitude of reduced efficacy can be minimized or eliminated by applying the herbicides sequentially, increasing the graminicide rate, or applying more efficacious adjuvants. Grass species, plant size, and plant stress also can affect the magnitude of negative interactions. York and Wilcut (1995) reported that bentazon reduced control of yellow and purple nutsedge by imazethapyr.

Chloroacetamide herbicides can be applied postemergence without injuring peanut. While these herbicides provide residual control of grasses and some dicotyledonous and sedge weeds, they do not control weeds that have emerged. These herbicides can be applied with herbicides that have efficacy against emerged weeds. Dimethenamid-*P* and *S*-metolachlor did not reduce grass control by the graminicides clethodim or sethoxydim or the dicotyledonous and sedge herbicides acifluorfen, acifluorfen plus bentazon, or imazapic. However, visible injury caused by acifluorfen increased when acifluorfen was applied with chloroacetamide herbicides. Johnson *et al*. (1993) reported that injury from postemergence application of paraquat was not increased when following several chloroacetamide herbicides applied at planting, in contrast with injury observed when the herbicides were co-applied.

Compatibility of herbicides with other pesticides

Herbicide-Antidote Interactions: o

The herbicide antidote interactions are antagonistic in nature. The antidotes like NA, R-25788 and CDAA reduce the toxicity of Herbicdes like alachlr, EPTC and Butylate to certain plants (Crops).

Metribuzin activity on ivy leaf morning glory (*Ipomoea hederacea*) can be increased when the synergist PABA (picolinic acid t-butyl amide or MZH 2091) is included in the spray solution. Normally, ivy leaf morning glory is able to metabolize metribuzin via deamination followed by conjugation. However, in the presence of PABA, deamination is slowed and thus, ivy leaf morning glory is more susceptible to metribuzin.

Herbicide - plant growth regulator interactions

Prohexadione calcium is the primary plant growth regulator available for use in peanut. Efficacy of the herbicides acifluorfen, acifluorfen plus bentazon, bentazon, imazethapyr, imazapic, lactofen, and 2,4-DB was not affected by prohexadione calcium.

Herbicide- Insecticide Interactions:

Herbicide and Insecticides are often applied simultaneously or serially to crops within a short period. These chemicals are usually not harmful when used as per recommended practices. The tolerance of plants to a herbicide may be altered in the presence of insecticide and vice versa. The Phyto-toxicity of monuron and diuron is increased on cotton when applied with phorate. Similar effects were also observed on oats. Combination of Organo-phosphate insecticide andAtrazine on phyto-toxicity appeared to involve an effect of the insecticides on herbicides absorption and translocation.

Corn root-worm insecticides and sulfonylureas:

The root-worm insecticide, terbufos (an organophosphate insecticide), is applied as an in-furrow treatment with corn seeds. This treatment enhances the activity of primsulfuron and thus, corn injury. Crop safety is lost because terbufos binds to cytochrome P450 enzymes in corn, so the crop is less able to detoxify the herbicide. To avoid this problem, growers were advised not to use an in-furrow type treatment or to use a new formulation of Counter called Counter CR (Controlled Release). Now growers can also use BT-resistant crops.

Insecticides and propanil:

Propanil activity on rice weeds can be increased with the addition of malathion (an organophosphate insecticide). Organophosphate insecticides can inhibit acyl arylamidase, the enzyme responsible for propanil metabolism. This approach also increases the likelihood of crop injury if too much enzyme inhibition occurs in the crop as well.

Timing of application of herbicides and insecticides overlap during much of the growth cycle of peanut. As with other crops, potential interactions between herbicides and insecticides applied in the seed furrow to control thrips and suppress plant parasitic nematodes can occur. Acephate and aldicarb applied in the seed furrow at planting did not affect injury potential of peanut following postemergence application of acifluorfen plus bentazon or bentazon; however, the insecticide phorate applied in the seed furrow enhanced visible injury associated with bentazon, although this injury was generally transient. Although interactions of nicosulfuron and pyrithiobac-sodium increased injury in corn and cotton, respectively. However, chlorpyrifos applied at planting did not affect peanut response to diclosulam, *S*-metolachlor, or flumioxazin applied preemergence or acifluorfen, acifluorfen plus bentazon, imazapic, or paraquat plus bentazon applied postemergence. Efficacy of graminicides can be affected by insecticides applied to peanut. Carbaryl and dimethoate applied postemergence in combination with sethoxydim reduced annual grass control; no adverse effect was noted when acephate was mixed with sethoxydim. Pyrethroid insecticides did not affect efficacy of postemergence herbicides.

Herbicide Interaction with Pathogens and Fungicides:

Herbicides interact with fungicides as the disease causing organisms. Dinoseb was known to reduce the severity of stem rot (White mould) in groundnut. Diuron and Atrazine which inhibit photosynthesis may make crops susceptible to tobacco mosaic virus. Where as diuron may decrease the incidence of root rot in wheat. Atrazine was found to have antagonistic interaction with the fungicide Dexon on many crops.

Similar to herbicides and insecticides, timing of application of postemergence herbicides and fungicides to control foliar and soil-borne diseases overlap considerably during the peanut growing season. Fungicides are applied beginning approximately 45 days after peanut emergence and can be applied until a few weeks prior to digging and vine inversion.

Efficacy of clethodim and sethoxydim can be reduced by co-application with copper containing fungicides or azoxystrobin, chlorothalonil, and pyraclostrobin. Fluazinam and tebuconazole did not reduce grass control compared with graminicides applied alone. Efficacy of herbicides that control dicotyledonous and sedge weeds is not generally affected by fungicides. As was noted for interactions of herbicides, weed species and size and plant stress can affect the magnitude of interactions between herbicides and fungicides.

Although not used in peanut, efficacy of glyphosate was not affected by azoxystrobin, pyraclostrobin, or tebuconazol. Weed control by metribuzin, rimsulfuron, and thifensulfuron-methyl applied to tomato was not affected by azoxystrobin or pyraclostrobin. However, pyraclostrobin increased tomato injury from thifensulfuron-methyl when co-applied. Chlorothalonil increased persistence of metolachlor in soil although cyproconazole, flutriafol, and tebuconazole did not affect dissipation of metolachlor.

Tillage and Cover Crop Effects on Herbicide Degradation

Management systems that include reduced tillage and cover crops are gaining popularity. These practices typically increase plant residues at the soil surface and organic matter in the surface soil. In turn, microbial activity is increased, and the soil develops a greater capacity to adsorb and retain many types of farm chemicals, including herbicides. Accordingly, tillage and cover crops variously affect the degradation of herbicides and their movement with surface water runoff and internal drainage.

Allelopathy and its application for weed management

Allelopathy is a biological phenomenon by which an organism produces one or more biochemicals that influence the growth, survival, and reproduction of other organisms. These biochemicals are known as **allelochemicals** and can have beneficial (positive allelopathy) or detrimental (negative allelopathy) effects on the target organisms. **Allelochemicals** are a subset of secondary metabolites, which are not required for metabolism (i.e. growth, development and reproduction) of the allelopathic organism. The term allelopathy **or Teletoxy** was introduced by Molisch (1937). *Parthenium* daughter plants exhibiting teletoxy to its parent plants is known as autotoxy. The word allelopathy is derived from Greek – allelo, each other and patho, an expression of sufferance of disease.

Allelopathy is characteristic of certain plants, algae, bacteria, coral, and fungi. Allelopathic interactions are an important factor in determining species distribution and abundance within plant communities, and are also thought to be important in the success of many invasive plants.

Allelochemicals are found to be released to environment in appreciable quantities via root exudates, leaf leachates, roots and other degrading plant residues, which include a wide range of phenolic acids such as benzoic (1) and cinnamic acids (2), alkaloids (3), terpenoids (4) and others. These compounds are known to modify growth, development of plants, including germination and early seedling growth.

Allelochemicals appear to alter a variety of physiological processes and it is difficult to separate the primary from secondary effects. There are increasing evidences that allelochemicals have significant effects on cell division, cell differentiation, ion and water uptake, water status, phytohormone metabolism, respiration, photosynthesis, enzyme function, signal transduction as well as gene expression. It is quite possible that allelochemicals may produce more than one effect on the cellular processes responsible for reduced plant growth. However, the details of the biochemical mechanism through which a particular compound exerts a toxic effect on the growth of plants are not well known.

Allelochemicals are released in the form of:

Vapour (released from plants as vapour): Some weeds release volatile compounds from their leaves. Plants belonging to labiateae, compositeae yield volatile substances.

Leachates (from the foliage): From *Eucalyptus* allelo chemicals are leached out as water toxins from the above ground parts by the action of rain, dew or fog.

Exudates from roots: Metabolites are released from *Cirsium arvense* roots in surrounding rhizosphere.

Decomposition products of dead plant tissues and warn out tissues

The production of allelo chemicals is influenced by the intensity, quality and duration of light. Greater quantity produced under ultra violet light and long days. Under cropped situation low allelo chemicals. Greater quantities are produced under conditions of mineral deficiency, drought stress and cool temperature more optimal growing conditions.

Commercial herbicides based on natural products

Herbicides and agrochemicals based on natural products are attractive for a variety of reasons. Most biologically active natural products are at least partially water-soluble and, as a result of natural selection, more likely to exhibit some bioactivity at low concentrations. Natural products are frequently considered to be environmentally benign, but many plant and microbial compounds are potent mammalian toxins. Many allelochemicals exert their influence through mechanisms not possessed by commercial herbicides, making them ideal lead compounds for new herbicide discovery. Unfortunately, the complex structures of most secondary metabolites, usually containing several stereocenters, complicate structural characterization and make the feasibility of economical, large-scale synthesis of the compound questionable. Structural simplification of the lead compound often results in significantly lower biological activity. These issues, of course, are the same ones encountered in the pharmaceutical industry, but the pesticide industry has shown only modest interest in the natural product-based discovery approach to herbicides. Most of the effort that has been expended concerns natural products obtained from microbial sources rather than higher plants.

1. Organophosphorous compounds

Two herbicides based on natural products isolated from bacteria have been commercialized to date: bialaphos and phosphonthricin . The ammonium salt of synthetic racemic is glufosinate, marketed under a variety of trade names. Bialaphos (also known as phosphonthricylalanyl alanine) was originally isolated from different *Streptomyces* strains by two independent groups and is currently marketed in Japan under the name Herbiace. Although not a natural product, the widely used herbicide glyphosate bears a striking structural resemblance . Another phosphonate natural product, phosphonothrixin , was recently isolated from *Saccharothrix* sp. ST-888 and exhibits phytotoxic activity against a variety of plants.

2. Triketones

Leptospermone is a major component in the essential oil of the plant *Leptospermum scoparium* found in Australia and New Zealand. The triketone herbicides, including sulcotrione and mesotrione , are post-emergent broadleaf herbicides based on the leptospermone structure template that inhibit *p*-hydroxyphenylpyruvate dioxygenase (HPPD). The herbicidal activity of these compounds correlates well with their acidity, accounting for the electron withdrawing substituents on the benzoyl moiety of these compounds.

3. Cinmethylin

The monoterpene ether 1,8-cineole is a major component of the essential oils of a number of plant species, and was one of the first compounds implicated as an allelochemicals.

i) Benzoquinones

Sorgoleone and its hydroquinone form are allelochemicals exuded from the roots of sorghum. Compound was the first natural host germination stimulant for the parasitic weed *Striga asiatica* (witchweed) to be isolated and characterized and has been the subject of a total synthesis. Sorgoleone is highly phytotoxic and inhibits chlorophyll formation and photosynthetic oxygen evolution.

ii) Coumarins and flavonoids

Coumarins and flavonoids are ubiquitous in plants, and several have been implicated in allelopathic interactions. Coumarin and its derivatives such as scopoletin are known inhibitors of seed germination and growth of various plants, and **blocked** mitosis in *Allium cepia* (onion). Coumarin and the furanocoumarin psoralen are components of *Ruta graveolens* (Rue), a medicinal plant with allelopathic properties. Psoralen can inhibit lettuce seed germination of at a concentration of 1 ppb.

The allelopathic activity of compounds isolated from *Melilotus messanensis* (sweet clover) has been the subject of several investigations. Several flavonoids and a coumarin isolated from sweet clover were recently subjected to bioassay, but their observed activities were low, suggesting that triterpenes and saponins are responsible for the activity of sweet clover.

iii) Terpenoids

Tens thousands of isoprenoid compounds are known and hundreds more are reported in the literature each year. Therefore, it is not surprising that these secondary metabolites have been examined for their allelopathic potential. This topic has been the subject of past reviews.
Messagenic acids A–I (**30**–**38**) are a family of nine lupane triterpenes isolated from sweet clover along with the oleanane triterpenes melilotigenins B–D (**40**–**42**). Messagenic acids D, F, and G (**33**,**35**, **36**) were prepared via semi-synthesis from the more plentiful betulinic acid (**39**) in order to supplement the minute amounts of the natural material available. These compounds were assayed for seed germination and growth activity using both mono- and dicotyledons. The compounds tested showed insignificant effects on lettuce but inhibited the seed germination of *Hordeum vulgare* (barley) and stimulated seed germination of *Allium cepa* (onion).

iv) Strigolactones

Parasitic weeds of the *Striga* (witchweeds), *Orobanche,* and *Alectra* families affect a number of important cereal and legume crops, causing dramatic reduction in yield and in severe cases complete destruction of the crop. The problem is especially severe in Africa and is becoming more prevalent. The seeds of these parasites only germinate in the presence of chemicalstimulants exuded from other plants. Typically the host plant is the source of seed germination stimulant, but the first such germination stimulant to be characterized, strigol (67) was in fact isolated from a non-host plant. The first seed germination stimulant isolated from a *Striga* host (*S. bicolor*) was the hydroquinone form of sorgoleone (19). Structurally related witchweed seed germination stimulants sorgolactone and alectrol were isolated from sorghum and *Vignaunguiculata* (cowpea) respectively, and assigned structures 68 and 69. Both of these compounds were obtained in minute quantities and the structures were assigned based on spectral data correlated with data from strigol (67), whose structure had been confirmed by X-ray analysis.

Allelochemicals from sunflower

Few plants have been studied as much in recent years for their allelopathic potential as the sunflower,*Helianthus annuus*. Sunflowers are an important crop in many parts of the world, and dozens of hybrid varieties are known, 26 in the Andalusia region of Spain, for example. Leather conducted some of the first studies on this species, and showed that sunflower extracts inhibited germination of growth of a variety of weed species. *H. annuus* has activity against such troublesome weeds as morning glory, velvetleaf, pigweed, jimson weed, wild mustard, and others. Subsequent research has included examination of the effects sunflower growth stage has on the allelopathic effects, and examination of other sunflower species.

1-**Heliannuols**

The heliannuols, are a promising group of phenolic allelochemicals isolated from *H. annuus*. The phenolic functional group has long been associated with allelopathic activity. Heliannuol A was isolated from an aqueous extract of *H. annuus* L. var. SH-222 and has a novel sesquiterpenoid skeleton consisting of an eight-membered cyclic ether fused to a benzene ring. Heliannuols B, C and D were isolated shortly thereafter, all containing a seven-membered benzofused cyclic ether. Heliannuol E has a vinyl substituent, and is the only heliannuol that contains a six-membered benzofused ether. Heliannuols F–K have more highly oxidized benzofused ether rings, but are present in minute quantities—extraction of 6 kg of fresh sunflower leaves yielded only 1–2 mg.

2- **Sunflower terpenoids**

Sesquiterpene lactones are common constituents of *Helianthus* species. Annuolides A–G are a family of guaianolides isolated from sunflower cultivars that exhibit allelopathic activity. Bioassay data indicated that the α-methylene lactone was not strictly required for inhibiting lettuce seed germination but the compounds with the α-methylene moiety were active at lower concentrations. Derivatization of the hydroxyl group closest to the methylene lactone as in annuolides F and G reduced activity.

Sunflower flavonoids

The sunflower has also yielded chalcones and flavonoids in the search for allelochemicals. Chalcones kulkulkanin B and heliannone A were isolated from both *H. annuus* cultivars VYP

Allelopathic control of certain weeds using Botanicals

For instance Dry dodder powder has been found to inhibit the growth of water hyacinth and eventually kill the weed. Likewise carrot gross powder found to detrimental to other aquatic weeds. The presence of marigold (*Tagetes erecta)* plants exerted adverse allelopathic effect on *Parthenium* spp. growth. The weed coffeesena (*Cassia* sp) show suppressive effect on *Parthenium*. The eucalyptus tree leaf leachates have been shown to suppress the growth of nut sedge and bermuda grass.

Allelopathic effects of weeds on crop plants

Root exudates of Canada thistle (*Cirsium* sp.) injured oat plants in the field

Root exudates of *Euphorbia* injured flax. But these compounds are identified as parahydroxy benzoic acid

Maize

Leaves & inflorescence of *Parthenium* sp. affect the germination and seedling growth

Tubers of *Cyperus esculentus* affect the dry matter production

Quack grass produced toxins through root, leaves and seeds interfered with uptake of nutrients by corn

Sorghum

Stem of *Solanum* affects germination and seedling growth

Leaves and inflorescence of *Parthenium* affect germination and seedling growth

Wheat

Seeds of wild oat affect germination and early seedling growth

Leaves of *Parthenium* affects general growth

Tubers of *C. rotundus* affect dry matter production

Green and dried leaves of *Argemone mexicana* affect germination & seedling growth

Sunflower

Seeds of *Datura* affect germination & growth

1) Effect of weed on another weed

Thatch grass (*Imperata cylindrica*) inhibited the emergence and growth of an annual broad leaf weed (*Borreria hispida*).

Extract of leaf leachate of decaying leaves of *Polygonum* contains flavonoides which are toxic to germination, root and hypocotyls growth of weeds like *Amaranthus spinosus*
Inhibitor secreted by decaying rhizomes of *Sorghum halepense* affect the growth of *Digitaria sanguinalis* and *Amaranthus* sp.

In case of *Parthenium*, daughter plants have allelopathic effect on parent plant. This is called AUTOTOXY

2) Effect of crop on weed

Root exudates of wheat, oats and peas suppressed *Chenopodium album*. It increased catalase and peroxidase activity of weeds and inhibited their growth.

Cold water extract of wheat straw reduces growth of *Ipomea* & *Abutilon.*

3) Stimulatory effect

Root exudates of corn promoted the germination of *Orbanchae minor*; and *Striga hermonthica*. Kinetin exuded by roots sorghum stimulated the germination of seeds of *stirga asisatica*
Strigol – stimulant for witch weed was identified in root exudates from cotton.

Integrated Weed Management

Integrating multiple weed control tactics into a single weed management program, optimizing control of a particular weed problem. The past several decades have seen simplified weed control practices that rely heavily on a few popular herbicides. However, the rapid spread of herbicide-resistant weeds has required farmers to incorporate alternative weed management approaches. While many farmers are incorporating different herbicides, this is likely to have only short-term success. Using non-herbicide approaches in combination with multiple, effective sites of action is needed for long-term success.

Why is IWM Necessary?

It might be better to first discuss why weed control is necessary. Weeds negatively impact crop yields, interfere with many crop production practices, and weed seeds can contaminate grain. Based on national research, corn and soybean yield can be reduced by approximately 50% without effective weed control.

Herbicide application is the main weed control strategy used. Reliance on this one method has led to the development of herbicide-resistant weeds. There are a limited number of herbicides available to use and cases of herbicide resistance are rapidly increasing in the US. As a result, herbicides are in need of extra help to continue to ensure adequate weed control.

IWM tactics span a wide range of options and complexity. Many IWM tactics can be integrated without substantial change to current management programs, while others require more extensive planning and implementation. Some options that are easier to implement include: equipment cleaning, timely scouting, altering herbicide tank mixes; while more extensive options include: changing crop rotation, cover cropping, changing tillage practices, and harvest time weed seed control.

Components of an IWM Plan:

The goal of IWM is to incorporate different methods of weed management into a combined effort to control weeds. Just as using the same herbicide again and again can lead to resistance, reliance on any one of the methods below over time can reduce its efficacy against weeds. Two major factors to consider when developing an IWM plan are (1) target weed species and (2) time, resources, and capabilities necessary to implement these tactics.

While it is wise to be a good steward of herbicide technology, through the use of PRE and POST herbicide applications or tank mixes, IWM requires the use of tactics beyond herbicides. For example, using these herbicide application practices along with a winter cover crop or harvest weed seed control (HWSC) and prevention methods would be considered IWM.

Prevention, Cultural ,Chemical ,Biological ,Mechanical (IWM)

IWM is composed of mechanical, cultural, chemical and biological tactics. Graph credit: Annie Klodd

Categories of IWM Practices:

Prevention

Prevention is one of the first steps of weed management. This category is unlike the others in that it focuses on keeping weeds out of the field or spreading within a field.

Growers can incorporate this tactic by:

- **Avoid inputs** contaminated with weed seeds, such as crop seed, manure, and other inputs.
- **Cleaning equipment**, including combines (**combine cleaning methodology**), that could transport weed seeds between fields.
- Preventing weeds from producing seeds in the field but also in ditches, fencerows, and other nearby non-crop areas.
- **Scouting** for weeds in a timely manner.
- Proceeding with caution when purchasing used farm equipment or using rented land.

Horseweed seed on bush hog after mowing a weedy field. These seeds can easily spread to other fields.

Cultural:

A healthy, vigorous crop is the best weed control. Cultural practices are designed to give the crop a competitive advantage over weeds.

Growers can incorporate this tactic by:

- **Reduced row spacing** so the crop can reach canopy more quickly to shade out weeds.
- **Crop rotation** to prevent weeds from adapting to the weed control tactics common in any one crop.
- Nutrient management to allow optimum crop uptake while denying weeds access to nutrients.
- **Cover crops** to compete with weeds for space, sunlight, nutrients, and water.
- Altered planting dates to give the crop a head start or allow for a flush of weed germination that can be controlled before planting.
- Crop variety selection to ensure crops have the utmost competitive advantage against weeds.

Horseweed suppression from a cover crop mixture compared to an area where no cover crops were planted.

Chemical:

Herbicides are an integral part of most weed management plans and will continue to be so, even in IWM programs.

Good management practices for applying herbicides include:

- Timely **scouting**.
- Proper **weed identification** and awareness of what herbicide-resistant weeds are in the area.

- Correct herbicide application, meaning applying the appropriate product at the right rate and at the right time.
- Maximized diversity through the **use of tank mixes** herbicides with **multiple, effective sites of action** (SOA) and by rotating herbicides throughout the season whenever possible.
- Plan ahead across seasons to avoid using herbicides with the same SOA repeatedly.

Mechanical:

Mechanical weed management focuses on physical practices that disrupt germination and destroy plant tissue.

Growers can incorporate this tactic by:

- Hand-pulling
- Tillage
- Burning
- Mowing
- **Robotic weeding machines**
- **Harvest weed seed control**, which reduces the input of weed seeds into the soil seedbank by destroying or removing seeds retained on the weeds at the time of harvest.

Hand pulling escaped weeds is critical to prevent seeds from entering the soil seed bank, particularly for herbicide resistant weeds such as Palmer amaranth.

Windrow burning, a form of harvest weed seed control, is an excellent tactic to prevent weed seeds from entering the soil seed bank. Picture: Michael Flessner, Virginia Tech

Harrington Seed Destructor: Two mills destroy weed seeds contained in the chaff portion that comes out from the combine.

Biological:

This tactic uses living organisms to target weeds including bacteria, fungi, or insects that have a preference for a certain weed species. This tactic is arguably the least used of all tactics but is the subject of much research. Cover crops can be considered a biological control tactic.

Integration of herbicide with non chemical methods of weed management

Ever since the first cultivation systems were developed for food production farmers of all generations and areas have been faced with the problems of non crop plants growing amongst the crops. These non-crop plants, which compete with the crops for moisture, light, nutrients and space, have long been known as weeds.

The problems which these non-crop plants have caused to farmers have led to the term weed being used as an insult to other humans, often inferring lack of courage or strength. Yet weeds which are thin, spindly and pale are often so because of their resilience and ability to compete with the crop plants. The trade names of herbicides developed to control weeds imply that they are a challenge worth combating, or names such as Avenge, Crusader, Harrier and Stomp would not be used.

With the much greater public awareness of food and environmental issues which has developed rapidly in recent years, it is probably worth looking at weed control from a wider perspective, and particularly at methods of weed control in systems where herbicides are too expensive or ineffective to use and in systems in which they are not permitted for use.

A weed can be thought of as any plant growing in the wrong place at the wrong time. In crops weeds can cause problems of severely reduced yields and also affect the efficient use of machinery, for example in harvesting and crop storage. Effective weed control is therefore an important part of crop husbandry, and has traditionally been a labour intensive operation. In less developed countries the situation still exists where the peak labour requirement is often for hand weeding. If this labour demand cannot be met, then the crop must be grown on a smaller area than would otherwise be economically viable.

Controlling weeds Weeds can be controlled through proper management, using simple implements and biological methods.

Proper crop management

1 Place fertilizer on the ground near the stem of crop plants. This will give nutrients only to the main crop, rather than to weeds.

2 Keep channels clear of weeds. This will reduce the number of weed seeds washed into your crop. It will also keep the water flowing freely. Good irrigation practices give crops a good start over weeds.

3 Grow crops in proper rotation to keep weeds down. Two to three short-duration crops should be grown in rotation in the same field. Change the crop rotation periodically (after a few years) to prevent problem weeds from establishing. Grow at least one soil-maintaining legume crop in each rotation If a problem season is expected, select a crop which will prevent weeds from growing.

4 Clean your seed to remove weed seeds. Destroy the weed seeds by burning or burying them.

5 Major sources of weed seeds are farmyard manure and compost. Weed seeds withstand partial decomposition. Therefore, apply only fully decomposed farmyard manure or compost to your fields.

Mechanical methods

1 Irrigate your field a few days before sowing the crop. Plough the field to destroy the weeds that emerge before sowing the crop.

2 A few implements are available which make weeding easier. Among these are the wheel hand hoe and Triphali. (See Drudgery-reducing implements for farm women.)

3 Burn weeds to get rid of accumulated vegetation or destroy dry tops of mature weeds. Burning will kill even green weeds and will destroy buried weed seeds.

4 Mulch the crop by spreading dry or green crop straw, sawdust, bark dust, and other plant parts. Paper, plastic sheets, or polythene films are also used as soil covers. This method is effective against annual and perennial weeds.

5 Flooding is used for weed control in fallow rice fields. Surround the weed-infected area with dikes, and maintain the water at 15-30 cm depth for 3 to 8 weeks.

Biological weed control

1 Some crops which grow rapidly have an advantage over slow-growing or late-emerging weeds. Such crops include maize, sorghum, soybean, and cowpea.

2 Weeds face tough competition when the crop plant population is high. Plant population can be increased by reducing the row spacing or plant-to-plant spacing within the row. This has a smothering effect, reducing weed emergence and establishment.

3 Bio-control agents, like azolla, can also be used to control weed populations in rice fields.

Conclusion

Weeding has traditionally been a labour intensive operation in crop production. The use of herbicides was rapidly accepted by many farmers and became an accepted part of crop husbandry, although a few farmers always questioned the widespread use of chemicals in farming, and the concept of organic farming necessitated a non-chemical approach to weed control.

The recent upsurge in environmental awareness of the public, interest in organic food production and some problems with herbicide use, has led to a range of techniques and machines being developed for non-chemical weed control. Thermal and mechanical techniques are reviewed for cereal and row crop production.

Weed control and environmental issues

As agriculture became mechanised cultivation techniques for weed control were developed, particularly for inter-row work in widely spaced row-crops. A significant amount of manual work was still required for the weeds in the crop rows, although steerage hoes were used for the inter-row areas. To control couch (Agropyron repens) and other rhizomatous weeds, intensive cultivations were practiced, particularly using "L" blade rotary cultivators . Inter-row cultivations for weed control in potatoes can cause problems of clod formation and variations on the traditional equipment design were developed.

The huge reserve of weed seeds in the soil means that any cultivation operation will stimulate another flush of weeds to germinate. The nature of the growth of the crop plants then becomes an important factor. Leafy growth which spreads to cover the ground can effectively smother the weeds but crops such as onions, which have thin leaves tending to stay well above the soil surface, are prone to severe weed competition.

It is therefore hardly surprising that the development of chemicals to act as herbicides gained rapid acceptance among farmers, as successful weed control is a major contribution to a successful crop. Extremely toxic substances, such as sodium arsenite and DNOC, one of the first selective herbicides, were succeeded by translocated and growth affecting chemicals like MCPA, which is less toxic to animals. Persistent and residual herbicides, such as simazine and the longer lasting linuron, are now available for appropriate applications. However, in the 1960's concern was already being shown over the environmental effects of pesticides in general, and insecticides in particular. Herbicides were also investigated, and studies in the USA as long ago as 1959 showed aminotriazole, a translocated weedkiller, to be carcinogenic.

WEED COMPETITION

At this stage it is worth considering some basic aspects of weed management, before looking in detail at the techniques available for non-chemical weed control. An awareness of the common weeds in the different fields is important, so operations such as cultivations, sowing and weeding can be timed according to the peak germination periods of the predominant species . In continuous cereals the range of weeds is often reduced to those whose cycles fit with that of the cereal crop. For example, if cleavers (Galium aparine) are a major problem, then the sowing of winter cereals should be delayed until after their peak time for germination. Crop rotations should be designed so that the differences in the timing of seedbed cultivations prevent one weed species becoming dominant.

The total absence of weeds has only become a possibility following the introduction of herbicides. However, the complete removal of weeds from within a crop may itself cause other problems. Insects then have no alternative but to attack the crop itself and there is no suitable cover for the predators of crop pests . Agronomists and statisticians have yet to agree on the effect on crop yield, or the cost/benefit analysis, of the presence of low weed densities.

Non-chemical weed control

It is extremely difficult to put a price on the research and development costs of the herbicides used in agriculture today. It would not be a gross exaggeration to state that less than 1% of that cost has been spent on the development of non-chemical weed control methods and yet the major food retailers expect their sales of organically produced vegetables to be at least No of total sales by the mid-1990's. Non-chemical weed control does not necessarily imply reverting to outdated techniques and an impressive array of modern machinery already exists, some of which are new ideas and others developments of more traditional implements. The role of these machines for effective weed control should now be examined as part of a weed management strategy.

Weed control in organic cereals

A good rotation is needed for pest and disease control, the maintenance of soil fertility, as well as for weed control. An example of a mixed farm 8 year rotation is:

- 3 years grass/clover ley

- 2 years winter wheat
- 1 year arable silage (cereals/legumes)
- 1 year potatoes
- 1 year potatoes 1 year spring barley (under sown)

The 3 year ley is to control annual weeds, while under sowing helps to smother weeds and provide soil cover in the winter.

The timing of sowing is important, and with winter wheat, autumn weed problems can be avoided by delaying sowing until late October or November. A cereal variety with long straw and an initially prostrate growth habit, which covers the ground quickly, enables the crop to smother the weeds. However, in organic production resistance to common diseases is a prerequisite for variety selection. Other techniques to smother weeds include increasing the sowing rate by up to 20%, sowing cereals in bands and, as in parts of mainland Europe, under sowing winter cereals with mustard.

Higher seed rates are desirable, not only to provide more competition for weeds but also to help compensate for any crop loss due to weed control cultivations after sowing. A thin-tined implement can be used for operations pre- and post-emergence. Blind harrowing, just before the crop emerges, aims to disturb weeds which have already germinated. Careful examination of the soil to examine the weed seeds is essential, otherwise germination of the weeds will be stimulated instead. Once the crop has reached the 3 leaf stage harrowing can be effective, with chain harrows or striegels being used at speeds up to 8 km/h. The draft requirement is low, and a work rate similar to that for herbicide application can be achieved for a similar effect at a reduced cost. Some harrows have adjustments for different levels of pressure on the soil, to match the prevailing conditions. Hoeing cereals is possible if the rows are spaced closer than normal drills allow, in bands, and between the bands a wider gap is left for a hoe . The overall sowing rate should be increased by 10% for this system. Mustard sown as a fast growing cover crop to smother weeds in autumn sown cereals is possible if severe frosts are certain to kill the mustard, to prevent it competing with the crop in the spring. It is also thought that mustard may have an allelopathic effect on weeds.

Further investigations into the natural enemies of weeds are likely to identify either insects or diseases which can be used as a form of biological control. Examples here are the effect of ground beetles on weed seeds in USA maize production and the use of the rust Puccinia chondrillina to control the weed Chondrilla juncea L, which had become a pest in Australian wheat and pasture areas .

Weed control in organic row crops

Many of the aspects of weed management already discussed are also pertinent for row crops. A wide range of machines exist for weed control in row crops and it is useful to consider the two major types separately.

Thermal techniques for weed control

The control of weeds in the crop row is a major problem in many organic crops. To combat this problem, thermal techniques pre-emergence of the crop are becoming more sophisticated and there are also some crop plants which can tolerate post-emergence treatment at specific growth stages.

Thermal techniques, often called flame weeding, generally use liquified petroleum gas (LPG), mostly propane, but in the 1950's work was also carried out using oil burners to reduce weed competition in bulb production. However, some experimental work has been carried out into the use of electricity, both as a heat energy source and for electrical shock treatment. Of the latter, two methods, spark discharge and electrical contact, are under development, both needing voltages of around 20 kV to be effective. An electrical contact machine to control sugar beet bolters has produced a plant kill rate of 40%, compared to 60% for chemical control. Only one machine of this type has been produced commercially and its capital cost makes its use uneconomical below 900 ha/annum. However, compared with chemical use there are no dangerous residues following the treatment and therefore no delay in subsequent operations. Also the field efficiency of the operation is high, as there is no requirement to refill sprayer tanks or, in the case of thermal treatments, exchange gas cylinders.

The high voltage required for these machines poses a hazard, which may be less of a problem if lower voltages were used to generate heat to expose weeds to infra-red radiation. Laboratory investigations into the effects of different infra-red wavelengths on plants, identified a medium wave tubular fused quartz emitter to be the most effective of the infra-red emitters tested. Energy intensities between 200 and 400 kJ/m2 were required to severely affect plant growth at the seedling stage, with dicotyledons more susceptible to heat than monocotyledons.

LPG fuelled flame weeders have now become established as part of the organic grower's machinery complement. The aim of a flame weeding operation is not to burn off the weeds but to apply sufficient heat to severely damage the plant cells so the plant will eventually wither and die. The technique involves raising the plant tissue to a temperature of 100°C for 0. is, in order to burst the cell membranes.

Inter-row cultivations

There are a large number of different designs of inter-row cultivators available on the European market, varying from traditional spring-tine cultivators to novel pto-powered brush type machines. The basic requirements for successful inter-row cultivations for weed control are:

i) To cut or uproot weeds, and then either completely bury them or leave them on the soil surface for desiccation;

ii) To protect the crop plants;

iii) To control implement direction; iv) to control implement depth;

v) To maintain or improve soil conditions .

Although inter-row cultivations are normally used to control weeds between the crop rows, some investigations have been carried out to control weeds in the row. Setting the implement to direct soil into the crop row to cover small weeds was as satisfactory as herbicide use. Mechanical gappers and thinners, widely used before herbicide development, have yet to come back into favour for weed control in the rows. In the development of a new hoe ridger, experiments on plants grown in trays showed a 90% kill rate in dry conditions, 57% by incorporation and 33% by desiccation. This hoe ridger was designed for use in the later stages of sugar beet growth, and a similar effect is claimed for the ground driven rolling cultivator . This versatile machine can be operated at speeds up to 12 km/in and set to direct soil into the crop rows, to ridge soil, to cut down ridges, or simply to disturb weeds between the rows. The blade design produces a cutting and mixing effect, the depth of work was insufficient to control larger weeds and that the correct setting and operation of all inter-row cultivators influenced the results.

Steerage options are available for rolling cultivators, brush weeders and fined cultivators. The advantage is to be able to work closer to the crop rows without causing plant damage, but the effect of soil disturbance close to the root zone has yet to be quantified in terms of plant growth. The design of guards used to protect the crop leaves can vary from rotating discs to floating shields or tunnels. The crop needs protecting both from soil thrown by the tines and from the tines themselves.

Other techniques

Light exclusion techniques are widely used in small scale horticultural organic crop production. Materials used include black plastic, carpet, straw, cardboard, tree bark and wood chippings. The effects of such mulches on weeds, pests and crop yields, have recently been studied by several workers. In their study, different surface mulches for their effect on clearing an established grass pasture and subsequent crop yields for organic horticultural produce, its also increase available nutrient levels in the soil, yields and fruit flavour in apple orchards.

CONCLUSIONS

Techniques for non-chemical weed control have been developed to reduce chemical costs in conventional agriculture, in response to environmental pressures and to provide for the needs of organic food production. A wide range of equipment is available to cover the major crops grown. Successful non-chemical weed control requires a well managed, integrated system and attention to detail.

Future work is required to research the effects of heat from thermal techniques on soil micro organisms, and weed seed germination and viability. The effects of the different soil/weed/tine combinations on the success of the weeding operation and on the soil structure also merit attention.

Why are weeds important?

In a review of crop losses due to pests, it was stated that: ‘overall, weeds produced the highest potential loss (34%) with animal pests and pathogens being less important (losses of 18% and 16%) (Oerke 2005). Herbicides accounted for 46% of global pesticide sales in 2005, with insecticides (26%) and fungicides (23%) accounting for smaller proportions of the $33,600 million total spend (Agrow 2006).

The increasing importance of non- chemical methods of weed control

While herbicides are considered the main means of weed control in many countries, there is increasing recognition that their use will have to be integrated with greater use of non-chemical methods. In Europe, the three reasons why farmers will have to adopt more non-chemical weed control methods are:

1. Fewer herbicides available due to past European Union (EU) regulatory actions, and lack of new modes of action.
2. Increasing resistance, especially in grass-weeds such as *Alopecurus myosuroides* Huds. (black- grass) and *Lolium* spp.
3. New EU regulatory actions requiring farmers to adopt Integrated Pest Management (IPM).

Availability of herbicides in Europe Past Euro- pean Union (EU) legislation on pesticides had a big impact on the number of pesticides available, from 945 active substances to 336, a 64% reduction. The majority were eliminated because dossiers were either not submitted, were withdrawn or the pesticide failed the review on issues relating to human health or the environment. Major herbicides no longer available in Europe include atrazine, paraquat, simazine and trifluralin.

Herbicide resistance In Europe, 62 weed species have evolved resistance to herbicides in a total of 21 countries. Of resistant species, 32% are grass-weeds, notably *Alopecurus myosuroides* Huds. (black-grass), *Lolium multiflorum* Lam. (Italian ryegrass), *L. rigidum* Gaudin. (annual ryegrass), *Avena* spp. (wild oats) and *Apera spica-venti* (L.) P.Beauv. (loose silky-bent). Resistant *A. myosuroides* is the major problem in many countries in western Europe, with resistance to ACCase inhibitors widespread in the UK and France, and increasing in several other countries.

The formulated mixture of the two sulfonylurea herbicides, mesosulfuron + iodosulfuron ('Atlantis'), was introduced into France in 2002 and the UK in 2003, and is being used widely. In the UK, it was applied to 50% of winter wheat crops in 2008 (Garthwaite *et al*. 2008). Resistance to mesosulfuron + iodosulfuron had been identified in 293 populations of *A. myosuroides* in the UK by 2008 (Hull *et al*. 2008). ALS target site resistance (Pro197 and Trp574) has been confirmed in both the UK and France (Marshall and Moss 2008) and there is increasing evidence of enhanced metabolic resistance.

Increasing resistance, and the absence of any new modes of action, means that herbicide options for grass-weed control are being depleted rapidly. In the UK, the proposition that some degree of resistance occurs in all *A. myosuroides* populations regularly treated with herbicides, is not challenged by any of the major agrichemical companies.

Integrated pest management (ipm)/ integrated weed management (iwm)

Despite there being over 65 existing definitions of IPM (Ehler 2006), the EU felt obliged to produce yet another: 'Integrated Pest Management means careful consideration of all available plant protection methods and subsequent integration of appropriate measures that discourage the development of populations of harmful organisms and keep the use of plant protection products and other forms of intervention to levels that are economically and ecologically justified and reduce or minimize risks to human health and the environment' (CRD 2010). Member states are required to produce National Action Plans setting quantitative targets and indicators aimed at reducing the impact of pesticides on human health and the environment. The implementation of Integrated Pest Management is obligatory, and low pesticide-input pest management must be promoted, with priority given to non-chemical methods of plant protection wherever possible. To encourage compliance, member states are required to determine appropriate penalties that are 'effective, proportionate and dissuasive' (CRD 2010).

Integrated Weed Management (IWM) can be considered one component of IPM, and has been described as the application of numerous alternative weed control measures, which include cultural, genetic, mechanical, biological and chemical means of weed control. However, IWM makes no attempt to integrate management of pests other than weeds, its use should be discontinued. He acknowledges that current IPM programmes do not achieve this level of integration. This view is supported by perusing recent editions of IPM Net News, which has provided global Integrated Pest Management information since 1993. Very few articles feature more than a single pest category, and most deal with a single pest species.

The potential of non-chemical weed control methods

Lutman and Moss recently completed a review of non- chemical methods for control of grass-weeds in the UK for Syngenta (unpublished). The weeds included were: *A. myosuroides* (black-grass), *Avena* spp. (wild oats), *Bromus* spp. (bromes) and *Poa annua* L. (annual meadow-grass). Most information was available for *A. myosuroides* in winter wheat and the results are summarized in Table .

Table Non-chemical control of *A. myosuroides* in rotations based on winter wheat (number of comparisons in brackets).

Method	% reduction achieved	
(no. of comparisons)	Mean	Range
Ploughing (25)	67%	−20% to 96%
Delayed drilling (16)	37%	−64% to 82%
Higher seed rates (15)	30%	+8% to 53%
Competitive cultivars (4)	27%	+9% to 36%
Spring cropping (2)	80%	–A
Fallowing (1)	70%	–

[A] – insufficient information.

Although this weed is mainly a problem in Europe, the levels of control achieved by the different non- chemical methods are likely to be broadly similar for other annual grass-weeds in many countries. Consequently the implications of these results are potentially of much wider relevance. The results show that non-chemical control methods can give useful levels of weed control. They also highlight the great variability in efficacy between experiments, with negative control being possible. This can happen, for example, where mouldboard ploughing brings more seeds to the surface than it buries, with the consequence that the subsequent weed plant population is higher than where non-inversion tillage has been used.

The limitations of non-chemical weed control methods

It is informative to present the mean efficacy results in a different way, pretending that they are actually herbicides, rather than non-chemical means of weed control.

On herbicide labels in the UK, weeds are given a rating of S (susceptible), MS (moderately susceptible), MR (moderately resistant) or R (resistant) depending on their response to that product. Note that ‘resistant’ in this case refers to the inherent insensitivity of the ‘wild type’ weed. The UK regulators data requirement handbook specifies the level of weed control expected for product label effectiveness claims (CRD 2010).

For a label claim of 'susceptible', consistent control of 85% and above is required generally, but for pernicious grass-weeds where seed return must be prevented, such as *A. myosuroides* and *Avena* spp., 95% is required. For label claims of 'moderately susceptible' and 'moderately resistant', the respective control levels are 75–85% and 60–75%. Less than 60% control means that the weed must be listed as 'resistant' on the label.

Why has ipm/iwm failed to make more impact worldwide?

While there are undoubted cases of successful implementation of IPM and IWM, such as the 'push-pull' strategy for controlling pests and parasitic weeds of maize and sorghum in east Africa, there is a wide- spread view that neither has been adopted as widely as anticipated. IPM, as originally envisaged, has been implemented to any significant extent in America, Western Europe or Asia 'IWM is still not widely adopted'. Bearing in mind that the integrated pest management concept was first promoted over 40 years ago, how can we explain this apparent failure in uptake?

We can consider why farmers are reluctant to adopt more non-chemical methods of weed control by using control of *A. myosuroides* in wheat crops in the UK as an example. These factors provide a comprehensive explanation for the poor uptake of IPM worldwide, not only for weed control, but also for pest and disease control in many different crops. This may seem an ambitious claim, but it seems to me that, compared to non-chemical methods, pesticides are usually an easier, more reliable and cheaper option. Is it any wonder that farmers are reluctant to replace pesticides with non- chemical control methods which have mean efficacy levels equivalent to a very poor product, but often at a premium price?

A more detailed explanation of the factors listed in Table is justified. Clearly, these are generalizations, and there will be exceptions to each of these factors.

Table Reasons why farmers are reluctant to use non-chemical methods of weed control in place of herbicides.

- More complex to manage – time constraints
- Less effective than herbicides.
- Control levels more variable.
- More expensive than herbicides.
- Control levels less predictable.
- No compensation following control failure.
- May not reduce the need for herbicides.
- Little visible evidence of success.
- More risky, to consultant as well as farmer.
- Less return for supplier of herbicides.

- May have adverse environmental effects.
- Harder manual effort

More complex to manage – time constraints' If herbicides are replaced with several alternative methods, it is likely that the whole weed control program me will become more complex. The extra time needed to make management decisions may also be an important factor. The amount of time that can be spent, cost effectively, on weed related advice on any individual field is often very limited. In the UK, where most arable farmers use a crop consultant who advises on 4,000–6,000 ha of arable crops, it equates to, at most, 15 min ha^{-1} year^{-1} . The situation will differ in other countries with different farm sizes and agronomic systems, but the general principle of limited time availability for weed control advice at an individual field level will often apply. The time and cost of travelling to each field, and cost of collating and analyzing the data, needs to be considered. Such costs are nearly always ignored in research studies, but their omission raises serious questions about the economic validity of such studies.

Less effective, more variable, more expensive' non-chemical methods tend to be less effective, more variable and more expensive than pesticides for equivalent levels of efficacy. Although these relate specifically to *A. myosuroides*, I believe the principles are relevant to many other pest, disease and weed problems.

'More unpredictable' The control achieved by non-chemical methods can be very unpredictable. A technique that worked very well one year (e.g. delayed drilling to encourage weeds to germinate prior to sowing), may give very poor results in another year for reasons that are completely outside the farmer's control (e.g. dry conditions may prevent any weed germination). Pesticides too can give variable and unpredictable control, but agrichemical companies commit substantial resources to maximizing the consistency and performance of pesticides, which is usually superior to non-chemical methods.

'No compensation following control failure' If a pesticide fails to give adequate control, replacement or compensation from the supplier may be obtainable. This is common practice in the UK, provided that the pesticide has been applied correctly and in accordance with the recommendations. In contrast, compensation for failure of any non-chemical control method is highly unlikely, as it is much less obvious who is legally responsible.

'May not reduce the need for herbicides' None of the individual non-chemical control measures on their own can be expected to provide acceptable levels of weed control, so if herbicides still have to be used, a farmer my well question what has been achieved from the alternative methods. He, and his consultant, may have no clear idea whether any savings in herbicide use have been achieved.

Little visible evidence of success' A farmer will usually have no idea how successful a non-chemical method has been at reducing weed populations. In field experiments, differences may be obvious because one can compare different treatments side by side. How- ever, a farmer has, in effect, used a single treatment and cannot quantify its efficacy as he has nothing with which to compare it. With post-emergence herbicides (as with in-crop harrowing and hoeing), farmers can at least do some sort of 'before' and 'after' assessment. I believe this inability to quantify the efficacy of non- chemical control methods in commercial practice is a key, but largely unrecognized, factor responsible for the lack of adoption of IWM, and IPM more generally.

More risky to consultant as well as farmer' For all the reasons given above, it seems obvious that use of non-chemical control methods can be considered 'risky'. Farmers self-evidently need to minimize losses due to pests, diseases and weeds. Most farmers in the UK, as in many other countries, use a crop consult- ant or advisor for advice on crop protection. Some consultants are independent, purely supplying advice for a fee, while others are employed by agrichemical distributors who sell pesticides. Consequently, if use of non-chemical methods increase the risk of poor control, they are less likely to be promoted by independent consultants who need to maintain the confidence of their farmer clients.

Less return for supplier of herbicides' If a farmer's advisor is employed by an agrichemical supplier there will be an obvious, and even greater, conflict of interests than occurs with an independent crop consultant. The factors influencing decision making by farm consultants and advisors deserves greater recognition, as on many farms in the UK it is they, not the farmer, who makes many of the decisions relating to crop protection.

May have adverse environmental effects' Few would deny that use of pesticides can harm the environment. However, some non-chemical methods can be in conflict with a requirement to protect the environment. For example, mouldboard ploughing has advantages over reduced tillage systems for control of annual grass weeds. Conversely, reduced tillage systems are considered more sustainable in terms of soil and water conservation, carbon sequestration, mitigation of greenhouse gas emissions and maintenance of naturally occurring biocontrol agents. Consequently, non-chemical control methods are not immune from causing adverse environmental effects.

Harder manual effort' In highly mechanized farming systems, as in the UK, the relative manual effort of pesticide versus non-chemical approaches may be a relatively unimportant factor. However, it has some relevance in relation to hand roguing of weeds, such as *Avena* spp. In developing countries, the manual effort involved in hand weeding, as an alternative to using a knapsack sprayer to apply herbicides (e.g. glyphosate), may be all too apparent.

Does ipm = reduced pesticide use?

One common aim of IPM and IWM is to reduce pesticide use. Sometimes this is stated explicitly, while in other cases the aims are vaguer, as in the recent definition of IPM by the EU (in full above), which aims to 'keep the use of plant protection products and other forms of intervention to levels that are economically and ecologically justified'.

If the primary aim of IPM is to reduce pesticide use, then would it not be better to state this explicitly as the key objective? One could argue that other elements of IPM would then fall into place automatically. Whether this should be the primary aim, in a world with an increasing population and a finite land area subject to the negative consequences of global warming, must be questioned. It would certainly be easier to measure success or failure. For example, in the UK, pesticide usage surveys of arable crops show that the area sprayed with pesticides increased from 42.4 million spray ha in 1998 to 50.3 million spray ha in 2008, a 19% increase, whereas the weight of pesticides applied declined from 30,746 t to 18,758 t during the same period, a 39% decrease. There are different views on whether such changes are 'good' or 'bad', but few would argue with the survey data. In contrast, assessing the success of IPM implementation is fraught with difficulty. IPM as 'malleable', with the consequence that dif- ferent criteria can be used to serve different agendas, which can be used to 'prove' anything from 0% to 100% IPM compliance in the same farming system.

How successful member states of the European Union will be in assessing the success of IPM at reducing the impact of pesticides on human health and the environment', remains to be seen. Given that pesticides are subject to increasingly stringent approval procedures, it is highly unlikely that any benefits to human health will be proven. Success in achieving environmental benefits may be more likely, and will almost certainly be 'claimed', although linking these unambiguously with the new EU policy may prove rather more difficult.

Technology transfer and ipm/iwm

The successful implementation of an IWM system is highly dependent upon the efficient and thorough transfer of information and technology by education and extension. However, in the EU, most countries no longer have state extension services that could provide independent guidance and assistance to farmers and growers. Relying on commercial independent consult- ants and agrichemical distributors has its limitations, as detailed above.

In my opinion, there has been too much emphasis on research at the expense of extension. This is partly because extension is often seen as the 'poor relation' to research, attracting less funding and prestige. The pressure to publish, a result of misplaced academic elitism in many research institutions, means that the priority is the publication of results in 'high impact' journals, rather than ensuring any practical application.

It should never be forgotten that, however great the 'impact' of a publication, it achieves nothing in terms of improving our ability to manage pests, diseases and weeds until the information is actually used in practice. 'Knowledge without application is wasted' is a succinct summary of this problem. Too much knowledge, not enough application is, perhaps, a concise explanation for the lack of uptake of IPM/IWM worldwide.

Farmers do demonstrate the ability to effectively integrate education with experiential learning. Greater adoption of IWM may be achieved by greater attention to the farmer's perspective, and by framing messages in a manner that coincides with the farmer's experience and belief structure.

'Once viable IWM systems are developed, they must be demonstrated at the field level and a consistent message must be given by multiple people at multiple forums over multiple years. Patience is required by all involved, as meaningful change is usually a slow process.' Too often, it seems to me, insufficient time and resources are available to permit this 'slow proc- ess' of technology transfer. Indeed, the trend towards short-term projects, where the researcher's priority is often to identify sources of funding for follow-on projects, can only exacerbate this problem.

Weed management in major field crop

Paddy

Nursery

Apply any one of the Pre-emergence herbicides viz., Butachlor 2 l/ha, Thiobencarb 2/ha, Pendimethalin 2.5 l/ha, Anilofos 1.25 l/ha on 8th day after sowing to control weeds in the lowland nursery. Keep a thin film of water and allow it to disappear. Avoid drainage of water. This will control germinating weeds.

Transplanted Pre-emergence

- Use Butachlor 2.5 l/ha or Thiobencarb 2.5 l/ha or Fluchoralin 2 l/ha or Pendimethalin 3 l/ha or Anilofos 1.25 l/ha as pre-emergence application. Alternatively, pre-emergence application of herbicide mixture viz., Butachlor 1.2 l + 2,4-DEE 1.5 l/ha or Thiobencarb 1.2 l + 2,4-DEE
- 1.5 l/ha or Fluchoralin 1.0 l + 2,4-DEE 1.5 l/ha or Pendimethalin 1.5 l + 2,4-DEE 1.5 l/ha or Anilofos + 2,4-DEE ready mix at 1.25 l/ha followed by one hand weeding on 30-35 days after transplanting will have a broad spectrum of weed control in transplanted rice.
- Any herbicide has to be mixed with 50 kg of sand on the day of application (3-4 days after transplanting) and applied uniformly to the field in 2.5 cm depth of water. Water should not be drained for 2 days from the field or fresh irrigation should not be given.
- Wherever there is possibility of heavy weed infestation, herbicides can also be applied with neem coated urea which could serve as carrier, three to four days after transplanting instead basal application of N at last puddling.

Post-emergence

- If pre-emergence herbicides are not used, hand weed on 15th day after transplanting. 2,4-D sodium salt (Fernoxone 80% WP) 1250 g dissolved in 625 l/ha of water is sprayed with a high volume sprayer, three weeks after transplanting or when the weeds are in 3-4 leaf stage

Late hand weeding

- Hand weed a second time, 80-85 days after transplanting, if necessary.

Wet seeded rice

- In wet seeded rice apply Thiobencarb at 2.5 l/ha or Pretilachlor 0.9 l/ha on 4DAS/6DAS/8DAS followed by one hand weeding for effecrtive control of weeds OR Pre- emergence application of Pretilachlor + safener at 0.6 l/ha on 4DAS followed by one hand weeding on 40 DAS effectively control weed.

Rainfed rice

- First weeding should be done between 15th and 20th day and second weeding may be done 45 days after first weeding.or
- Use Thiobencarb 2.5 l/ha or Pendimethalin 3 l/ha 8 days after sowing if adequate moisture is available, followed by one hand weeding on 30 to 35 days after sowing.

Direct seeded rice

- Thiobencarb/Butachlor at 2.5 l/ha as pre-emergence application one day after wetting / soaking can be applied and it should be followed by hand weeding on 30th day. Sufficient soil moisture should be available for herbicidal use

Semi dry rice

- Use Thiobencarb 3 l/ha or Pendimethalin 4 l/ha on 8th day after sowing as sand mix if adequate moisture is available, followed by one hand weeding on 30-35 days after sowing

Or

- Pre-emergence application of pretilachlor 0.6 l/ha followed by post emergence application of 2,4-D Na salt 1.25 kg/ha + one hand weeding on 45DAS.

Sorghum

- Apply the pre-emergence herbicide Atrazine 50% WP 500 g/ha on 3 days after sowing as spray on the soil surface, using Backpack/knapsack/Rocker sprayer fitted with a flat fan nozzle using 900 lit of water/ha.
- Sorghum is slow growing in early stages and is adversely affected by weed competition. Therefore keep the field free of weeds upto 45days. For this, after pre-emergence herbicide application, one hand weeding on 30-35 days after sowing may be given.
- If pulse crop is to be raised as an intercrop in sorghum do not use Atrazine.
- Hoe and hand weed on the 10th day of transplanting if herbicides are not used. Hoe and weed between 30-35 days after transplanting and between 35-40 days for direct sown crop, if necessary.

Ratoon sorghum

- Remove the weeds immediately after harvest of the main crop
- Hoe and weed twice on 15th and 30th day after cutting.

Rainfed sorghum

Keep sorghum field free of weeds from second week after germination till 5th week. If sufficient moisture is available spray Atrazine @ 500 g/ha as pre-emergence application within 3 days after the soaking rainfall for sole sorghum while for sorghum based inter-cropping system with pulses, use Pendimethalin 3 l/ha.

Maize

Apply the pre-emergence herbicide Atrazine 50 at 500 g/ha (900 lit of water), 3 days after sowing as spray on the soil surface using Back-pack/Knapsack/Rocker sprayer fitted with flat fan or deflector type nozzle followed by one hand weeding 40-45 days after sowing. For maize + Soybean intercropping system, apply pre-emergence Alachlor at 4.0 l/ha or Pendimethalin 3.3 l/ha on 3rd after sowing as spray.

- Apply herbicide when there is sufficient moisture in the soil.
- Do not disturb the soil after the herbicide application.
- Hoe and Hand weed on 17th or 18th day of sowing if herbicide is not applied.

Note: If pulse crop is to be raised as intercrop, do not use Atrazine.

Wheat

The large-scale introduction and cultivation of dwarf cultivars of wheat led to the dominance of grass weeds which hitherto were contained by the traditional tall cultivars with greater canopy cover. Further, the increased fertilizer and irrigation application, which are pre-requisites for realizing the full potential of the crop and the ecological conditions of crop lands which have undergone a significant change leading to intensification of grassy weeds such as little seed canary grass (*Phalaris minor)* and wild oats (*Avena ludoviciana*) in wheat during the post-green revolution era. Rice-wheat cropping system occupies around 10.5 M ha area in India and plays a major role in sustaining the food security of the country, and weeds are the major threats for the sustainability of this system. Therefore, effective weed management is very essential.

Shift in weed flora

Weed flora in wheat has shown marked changes over the years because of repeated use of same herbicide, resource availability, and changes in cropping systems and tillage practices. Yellow thistle (*Carthamus oxyacantha*) was the major weed of wheat in 1960s, but resource availability and deep tillage have almost eliminated this weed. With the introduction of dwarf varieties of wheat, which are highly responsive to intensive irrigation and fertilizers, grassy weeds such as *Phalaris minor*, *Avena ludoviciana*, *Poa annua*, *Setaria viridis*, *Polypogon monspeliensis* and *Lolium temulentum* have become dominant. The development of a rice-wheat cropping system in India is the main reason behind the occurrence of *P. minor* as a major weed flora in wheat. Introduction of herbicides for weed control in wheat during 1980s and continuous use of isoproturon for the control of *P. minor* resulted in the evolution of herbicide resistance (Malik and Singh 1993). With successful management of isoproturon resistant *P. minor* biotypes with zero tillage and alternate herbicides like clodinafop, fenoxaprop and sulfosulfuron, broad-leaved weeds like *Rumex dentatus*, *Malwa parviflora* and *Medicago denticulata* are of great concern in irrigated wheat in rice-wheat cropping system in India.

Herbicides	**Dose (g/ha)**	**Time of application**	**Remark**
Pendimethalin	1000	0–3 DAS	For broad spectrum weed control
Isoproturon	1000	25–30 DAS	Effective on non-resistant biotypes of *Phalaris minor*
Clodinafop-propargyl	60	30–35 DAS	For controlling wild oats and *P. minor*
Sulfosulfuron	25	Do	For broad-spectrum weed control . Less effective against *A. ludoviciana* and *Rumex dentatus.* Residual toxicity damages succeeding maize.
Fenoxaprop-p-ethyl	100-120	Do	For controlling wild oats and *P. minor*.
2,4-D	500	Do	For broad -leaved weeds control. Less effective against *Malva* spp. *Solanum nigrum,Rumex dentatus, Anagallis arvensis* , *Melilotus indica* , *Medicago denticulate*. Should not be used in sensitive cultivars such as HD 2009
Metsulfuron-methyl	4	do	Broad-leaves weed control. Less effective against Malva parviflora and Solanum nigrum.
Carfentrazone	20	25-30DAS	For broad -leaved weeds control. Excellent control of *Malva* spp., *Physalis minima* and *Solanum nigrum* . Less effective against *Lathyrus aphaca*. Contact action, Weeds may regenerate.
Tralkoxydim	350	30-35 DAS	For annual grasses.
Triasulfuron	20	do	For controlling grasses and broad-leaved weeds. Pinaxaden- 40, 25–30 DAS For controlling wild oats and *P. minor*.

Maize, Sorghum and Pearlmillet

Maize and sorghum are major staple cereals (after rice and wheat) grown in both rainy (June-October) and post-rainy (November-February) seasons. Millets mainly pearlmillet (*Pennisetum* *glaucum*), finger millet (*Eleusine coracana*) and kodo millet (*Paspalum scorbiculatum*) are mostly grown during rainy season. Weeds are a major deterrent in increasing the productivity of these crops especially during rainy season. These crops are widely spaced, and during seedlings stage, they are comparatively small and grow slowly for the first 20–25 days and consequently do not compete well with most weeds in the early stage of crop growth, especially under adverse conditions.

Crop-weed competition and losses

Millets are very susceptible to competition from weeds early in the season. Therefore, initial weed control is essential. The average yield loss due to weeds ranges from 40–60% in maize, 15–83% in sorghum, 16–94% in pearlmillet and 55–61% in finger millet.

Control measures

Mechanical and cultural methods

Hand weeding or inter-row cultivation are the most widely followed methods of weed control in millets. But during rainy season, there are not many clear days and as a result, inter-culture operations are delayed, due to which, weeds overtake the crops and cause severe reduction in yield. Also with rising labour wages and non-availability of adequate labour at times required, it is becoming a serious problem to control weeds manually on larger area at the proper time.

Growing of legumes such as mungbean, groundnut, cowpea and soybean as intercrops in maize, sorghum / pearlmillet exert suppressing effect on weeds. Similarly narrow row spacing, use of higher seed rate, early application of nitrogen and its placement near to plants help in increasing vigour of the crop and exert smothering effect on weeds.

Herbicidal weed management

In no-till conditions, herbicides are becoming a major component of weed management in maize and grain sorghum as they improve weed control and production efficiency. Several herbicides have been evaluated in maize and sorghum . However in millets, the herbicide options are limited . At present atrazine is the only herbicide most commonly used for weed control in maize, sorghum and pearlmillet. Recently, two herbicides, viz. tembotrione and topramezone have been approved for post- emergence application in maize for controlling grassy weeds.

Herbicides recommended for millets

millets	Herbicide	Dose (kg/ha)	Time of application	Weeds controlled	Remarks
Pearl millet	Atrazine	0.50	Pre-emergence/early	Trianthema	For sole crop only
			post-emergence (10 DAS)	portulacastrum and E. colona	
	2,4-D	0.50–0.75	Post-emergence	Effective against	For sole crop only. Apply
				broad-leaved weeds	between 4–6 weeks after planting. Good as sequential application to
	Pendimethalin	0.50–0.75	Pre-emergence	Broad-spectrum	pre-emergence herb.Each supplemented with one hand
	Oxadiazone	1.0	Pre-emergence	weed control	weeding at 45 DAS
Finger millet	Oxadiazon	1.0	Pre-emergence	Broad-spectrum weed control	
	Isoproturon	0.50–0.75	Pre-emergence		
Kodo millet	Isoproturon	0.50	Pre-emergence	Broad-spectrum weed control	

Herbicides recommended for maize and sorghum

Herbicide	Dose (kg/ha)	Time of application	Weeds controlled	Remarks
Atrazine	0.75–1.0	Pre-emergence/ Early post-emergence	Broad-spectrum weed control. Some grasses are tolerant	For sole crop only. Does not control Acrachne racemosa, Brachiaria reptans and Commelina benghalensis
Alachlor	1.5–2.0	Pre-emergence	Effective control of grasses	Suitable for intercropping
Metolachlor	1.0–1.5	Pre-emergence	Effective control of grasses	Suitable for intercropping
2,4-D	0.50–0.75	Post-emergence	Effective against broad-leaved weeds	For sole crop only. Apply between 4-6 weeks after planting. Good as sequential application to pre-emergence herbicides
Paraquat	0.2–0.5	Post-em, directed	Broad spectrum weed	Effective against all weeds
Atrazine + pendimethalin	0.75 + 0.75	Pre-emergence	Broad-spectrum weed control	For sole crop only
Atrazine + alachlor	0.75 + 0.75	Pre-emergence	Broad-spectrum weed control	For sole crop only
Atrazine + metolachlor	0.75 + 0.50	Pre-emergence	Broad-spectrum weed control	For sole crop only

One supplementary weeding at 30 days after sowing following pre-emergence herbicides is required for broad-spectrum weed control and higher yields.