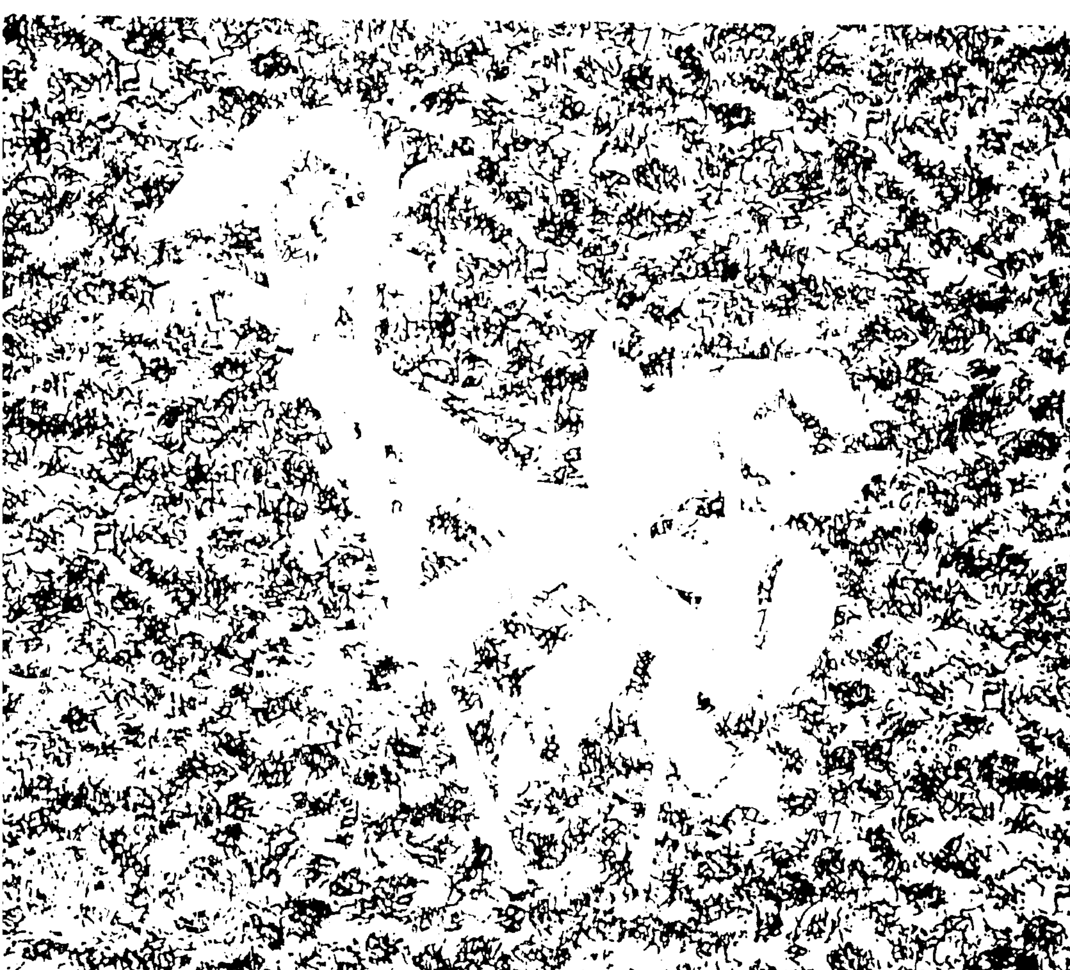
# INSTRUCTOR'S MANUAL

# FOR WEED MANAGEMENT



FOOD AND AGRICULTURE ORGANIZATION
OF THE UNITED NATIONS

UNITED NATIONS
DEVELOPMENT PROGRAMME

This manual has been prepared by the International Plant Protection Center of Oregon State University, Corvallis, Oregon, USA, in collaboration with FAO and UNDP, through its Action Programme for Improved Plant Protection, and with partial support from USAID.

It is intended to be a beginning outline for experienced instructors teaching weed management courses to extension staff and future trainers in developing countries where small-scale, arable-land farmers need to learn about improved land preparation and weed management technologies.

*FAO Training Series* *No. 12*

# Instructor's manual for weed management

**International Plant Protection Center**
**Food and Agriculture Organization of the United Nations**
**United Nations Development Programme**
**US Agency for International Development**

**FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS**
**Rome, 1986**

a

P-14
ISBN 92-5-102279-8

David Lubin Memorial Library Cataloguing in Publication Data

International Plant Protection Center, Corvallis, OR (USA)
Instructor's manual for weed management.
(FAO Training Series, no. 12)

1. Weed control. 2. Training courses.

I. FAO, Rome (Italy) II. UNDP, New York (USA) III. Agency for International Development, Washington, DC (USA) IV. Series

FAO code: 15 AGRIS: H60 C10 1986

ISBN 92-5-102279-8



Printed in Italy

# Contents


| | |
|---|---|
| Preface | vii |
| Introduction | ix |
| **1 COURSE ORGANIZATION** | 1 |
| Suggestions on procedure | 1 |
| Equipment and supplies | 4 |
| Treatment scheduling | 6 |
| **2 WEEDS: AN OVERVIEW** | 9 |
| Definition of weeds | 9 |
| The costs of weeds to society | 11 |
| Weed biology | 13 |
| Weed interference | 15 |
| Weed identification | 19 |
| **3 WEED CONTROL** | 21 |
| Methods of weed control | 21 |
| Biological control of weeds | 26 |
| Socio-economic considerations | 29 |
| Shifting weed populations | 32 |
| **4 APPLICATION OF WEED MANAGEMENT TECHNOLOGIES** | 35 |
| The safe use of pesticides | 35 |
| Chemical control of weeds | 40 |
| Principles of herbicide selectivity | 46 |
| Herbicide formulations | 52 |
| Adjuvants for herbicides | 58 |
| Pesticide mixtures | 61 |
| Herbicide application equipment | 64 |

Sprayer calibration 69
Herbicide calculations 73
Factors affecting soil-applied herbicides 75
Factors affecting foliage-applied herbicides 80
Herbicide families 86

5 CONSERVATION FARMING 103

The development of tillage 103
The tillage crisis 104
The evolution of conservation tillage 104
Research 105

6 RESEARCH STRATEGIES 107

Field research procedures 109
Evaluation of field research 112
Statistical analysis and research 116
Greenhouse and field experiments 117

7 WEED CONTROL IN CROPS 127

Information gathering 127
Plan of action 131

8 EXTENSION METHODS 133

APPENDIXES

Sample schedule 136
Sample review questions 140
Sample examination questions 145
Sample certificate 149

# Preface

The inspiration to write this book came as we prepared to teach course after course on weed management in developing countries. We knew the topics we wanted to cover in such a course and the inefficiency of preparing anew for each course was apparent.

It also became obvious that more than a few people must eventually organize and teach weed management courses if there were to be any hope of meeting the need worldwide. Surely we had acquired experience that would be useful to other instructors. There was a natural temptation to prepare a standard set of papers on the selected topics and encourage presentation of the same material time after time. But it was apparent that for each country, each course, and each group of participants, the needs varied. A standard set of material would not allow the flexibility so necessary to adapt to local conditions.

We hope the following pages are a workable compromise. They are intended to be a beginning outline for instructors. This is not a textbook. Furthermore, it was written with the assumption that the instructor will have extensive knowledge and experience in weed management. Ideally, the pages will be printed as an outline, with plenty of space for the instructor to add details and local examples.

We have used the first draft in this way and found it to be helpful in preventing an unnecessary duplication of material and as a reminder of important topics. We sincerely hope that each user will improve and expand this manual to make it even more useful.

*L.C. Burrill and M.D. Shenk*
International Plant Protection Center
Oregon State University
Corvallis, Oregon, USA

# Introduction

Possibly the greatest contrast in crop production between high-technology farming in developed nations and small-scale, subsistence farming in developing countries lies in land preparation and weeding methods. In developed countries, the use of improved technologies has allowed greater flexibility in crop production while maximizing the benefits of costly inputs of nutrients and moisture. For the first time in history, nearly optimal crop production is possible with minimal labour inputs. This has led occasionally to an overproduction of certain crops.

On the other hand, in developing countries, improved land preparation and weed management technologies have not reached the small-scale, arable-land farmer, who has been left with technologies that have altered little with time, that are extremely laborious and that at times exert an adverse effect on the agro-ecosystem. As a result, the great majority of farmers in these countries are not able to maximize inputs, and their economic status is not materially improving.

FAO recognizes these constraints and the inherent difficulties of transferring appropriate technologies owing to the lack of people with the desired expertise and the large number of small-scale farmers to be trained. To overcome these constraints and difficulties, FAO believes that there is no alternative but to direct a wider effort toward training at all possible levels. Any new technology, before being accepted at the farm site, must be correctly analysed, described, demonstrated, criticized, modified, and subsequently monitored.

Learning about new techniques is thus a slow, personal and social process. To accelerate this process, special training methodologies must be applied, which are based on past experience and which have proved successful.

FAO's *Instructor's manual for weed management* is based on many years of teaching and training experience. Its aim is to fill an existing gap, namely the lack of a suitable publication adapted to developing countries and capable of assisting in the training of a large number of extension staff and future trainers. If this manual can fill that gap, it will be of great help in the formidable task of transferring appropriate technologies to the millions of small farmers who have had little benefit from the modernizing of agriculture.

D.F.R. Bommer
Assistant Director-General
Agriculture Department
FAO

# 1 Course organization

## Suggestions on procedure

The following suggestions or ideas have proved useful in weed management training courses. Some, while obvious, are worth noting and all should be considered.

- Plan ahead

- Pursue funding and non-monetary support from several agencies and utilize the resources and strengths of each

- Select course participants whose backgrounds, interests and language capabilities are similar

- Select a location that is free of distractions and near field plot sites

- Select a location where comfortable housing and adequate food can be provided

- Schedule the course to minimize conflicts with the field work and national holidays of participants

- One or more instructors should visit local farms before the course to become familiar with weed problems and arrange for field trips with course participants

- Select topics that are appropriate to the background of the participants

- Organize a daily schedule that mixes class-room and field activities

- Plan and prepare appropriate practical exercises

- Insist on a high level of involvement by the course participants (attendance, punctaality)

- Do not give lectures; lead discussions

- Provide as many relevant publications as possible

- Minimize reliance on visual aids prepared in advance. They tend to structure the presentation and limit involvement by participants.

- Start each day with a review session. It will encourage night-time study.

- On the first day of the course, divide participants into groups of five to eight people. Many activities can be carried out in groups.

- The "core" instructors should be in the class-room (and field) whenever possible to be involved in discussions and ensure the continuity of presentations

- Start all sessions on time. Anyone who arrives late could be asked to answer a question from an earlier discussion.

- Use the expertise of local scientists when appropriate, but not to the point where control of course content is lost or the schedule is disrupted

- Remind invited speakers to stay within the assigned topic and alloted time

- Encourage invited speakers to use a discussion format. Often, speakers will not be comfortable with this technique. It is helpful if they sit in on several sessions before their own participation.

- Encourage chemical and equipment company representatives to participate by sponsoring social events such as dinners, or discussions of their products, research activities, and so on. Such events help break up the routine for participants in longer training courses.

- Start the course with an examination to determine the knowledge level of participants

- Take individual photographs of participants on the first day and have pictures printed as soon as possible so instructors can learn names. Individual participants appreciate receiving a duplicate print.

- Make sure all support activities such as transportation, food services and housing are adequate and timely

- Advise participants before their arrival of the nature of the course, any special conditions, and what will be expected of them:

  - the location of the course

  - the full schedule and the necessity of regular attendance

  - housing arrangements, including sharing rooms

  - the field-work requirement

  - financial details, including type of travel, expenses *en route*, and receipts needed

- Be especially sensitive to language barriers if visiting instructors or guest speakers are not thoroughly familiar with local customs, mores and language

- Take special care to involve participants who are especially timid or lack self-confidence

- Plan and prepare for an evaluation of the course

## Equipment and supplies

The following list is based on extensive experience and should be studied carefully. Items required for a course should be obtained well in advance. A normal training schedule leaves little time for shopping trips.

### *Useful supplies for a weed management course*

- Tape measure, 50 m, cloth reinforced with plastic; one for each group of six to eight people is very helpful
- Tape measure, 2-3 m
- Marking pens in various colours
- Plastic bags in various sizes
- Graduated cylinders, 25 cc, 100 cc
- Graduated pitchers, 2 l
- Scales to weigh small quantities of chemicals
- Spatulas for scooping powder formulations
- Pen, paper and portfolio for each participant
- Pipettes and bulbs
- Disposable gloves
- Heavy rubber gloves
- Rubber boots
- Assorted crop and weed seeds

- Stop watch
- Protective lab coats and dust masks
- Plot stakes
- Extension cords
- Blank plastic sheets for overhead projector
- Detergent and household ammonia
- Cotton twine, rubberbands and paper-clips
- Assortment of pots and trays for greenhouse projects
- Assortment of crops growing in pots
- Selected herbicides
- Assorted publications on weed management and research methods
- Buckets for carrying water
- Samples of herbicide labels
- Small calculators
- Blackboard, chalk and erasers
- Magnifying glass
- Stapler

***Useful equipment for a weed management course***

- Lever-operated knapsack sprayers, one for each group of four to six participants

- Knapsack sprayer, motorized
- Four-nozzle booms
- Assortment of nozzles and screens
- Assortment of hand-tools for field-work
- 35-mm slide projector
- Overhead projector
- Miscellaneous sprayers and other herbicide application equipment
- Transportation

## Treatment scheduling

Hands-on field experience in calibrating sprayers, spraying plots, and evaluating plant responses to weed control treatments is indispensable in a weed management training course.

However, since the plant responses to certain treatments may not be visible for 10-12 days, the instructors of short courses (less than a month) may be forced to schedule field-work and the use of herbicides for the first few days of the course. Instructors need to make clear that although a short course obligates the use of herbicides during the first few days, it should not be interpreted to mean that chemicals are more important than other methods of weed control. Time permitting, a more logical approach would be to cover weed control methods, biological and ecological factors influencing weed populations, weed control equipment, and field plot techniques and experimental procedures before beginning to use herbicides. In any case, the safe use of pesticides should always be dealt with before working with herbicides.

While this manual attempts to follow a logical sequence of topics within these limitations, it may be preferable to make other adjustments to meet local conditions, such as the dates on which invited discussion leaders are available, the availability of transportation and facilities. Experience also confirms that participants are more attentive if a day can include both class-room and field or laboratory exercises.

Often, non-class-room activities are advisable immediately following lunch. This helps participants overcome drowsiness which is common at this hour. Evening activities, if any, should be planned with participants. Practical exercises should be scheduled to follow immediately the study of principles or procedures.

# 2 Weeds: an overview

## Definition of weeds

This topic is a logical and ideal choice for the first lecture because it allows you to initiate a discussion format quickly for the course. Participants should suggest definitions of weeds. Little is lost if they are not precise; the participants are forced to think. Ask the group to comment on each definition proposed.

### *Some definitions*

- A plant out of place

- A plant not sown whose undesirable features outweigh its desirable features

- A plant or part of a plant interferring with the objectives of humans

- Any plant growing where it is not wanted

- A plant whose virtues have not yet been discovered

- An undesirable plant

- Oxford English Dictionary: a herbaceous plant not valued for use or beauty, growing wild and rank, and regarded as cumbering the ground or hindering the growth of superior vegetation

□ *Question:* Can a crop plant be a weed?

*Human perception and unwanted plants*

☐ *Discuss this concept:* Weeds occur only because of human attitudes.

– plants are considered weeds when they interfere with the utilization of land and water resources or otherwise adversely intrude upon human welfare

– usually this means that weeds are growing where other plants are supposed to grow or where no plants should be

***Positive value of weeds***

Considerable time will be spent on the negative value of weeds. Yet, it is important to consider some of the potential positive values of plants usually considered weeds.

☐ *Ask for examples of positive values of weeds.*

– erosion control

– food and cover for animals

– food for people

– medicines

– in adding organic matter to the soil

– in recycling nutrients from deep in the soil

– genetic material

– beauty

– host for beneficial insects

– nectar for bees

Participants should be urged to balance the costs and values of weeds when making judgements on control programmes.

☐ *Discuss the concept of "risk-benefit".*

## The costs of weeds to society

This section should emphazise that weeds are a serious constraint to crop production on a worldwide basis and that weeds also interfere with human activities in other ways.

The instructor should refer to a 1975 paper by C. Parker and J.D. Fryer, "Weed control problems causing major reductions in world food supplies", published in *FAO Plant Protection Bulletin*, vol. 23, no. 3/4, and also available as International Plant Protection Commission paper B/14 (in English), B/15 (in Spanish) and B/16 (in French). This paper reports an estimated average annual crop loss of 11.5 percent worldwide, for a total annual world loss of 287 500000 tonnes.

### *Agricultural losses*

It is difficult to determine the losses caused by weeds on a global scale. More meaningful estimates of production losses from weeds can be given for different kinds of agricultural systems: most developed — 5 percent loss; intermediate — 10 percent loss; least developed — 25 percent loss.

☐ *Discuss the ways in which weeds interfere with humans.*

- Direct costs of weeds

  – reduction of crop yields in the competition for light, moisture and nutrients, or by allelopathic effects

- reduction in the quality of harvested products: weed seeds in a seed or food crop; unpalatable, low-quality or poisonous plants in forages; green plant parts in dried seeds; weed burs in animal wool

- control costs

- poisoning of livestock

- reduction in flow of water in aquatic systems

- increased water loss from lakes and reservoirs

- Indirect costs of weeds

  - restriction on crops grown or area planted

  - harbouring of rodents, birds, etc.

  - host for crop diseases

  - host for harmful insects

  - fire hazard

- Non-agricultural costs of weeds

  - children miss school to weed crops

  - impaired visibility along roads

  - impaired human health

  - reduced land values

  - interference with aquatic and terrestrial recreational activities

□ *Question*: What are the types and magnitudes of losses from weeds in the country or region where the training course is being held?

□ *Question*: If weeds constitute such a serious constraint to crop production, why are there so few people trained as weed control specialists?

## Weed biology

The chance of finding the most effective and efficient control for particular weed species is improved as more is known about those weeds.

□ □ This session could be started by asking the participants what they would like to know about a weed species in order to plan a good control programme.

- Life cycle

  – this is less important in the humid tropics where weeds tend to grow all year

  – annuals: complete life cycle in one season (one year)

  – biennials: require two growing seasons to complete their life cycle

  – perennials: live for three or more years; simple perennials propagate and spread primarily by seed; creeping perennials propagate and spread primarily by vegetative means:

    · rhizomes = below-ground stem
    · stolons = above-ground stem roots
    · tubers = enlarged fleshy rhizomes
    · bulbs = large, fleshy leaf base

- Dissemination of weeds

  – water

  – wind

  – animals

  – people

□ □ This is the best time to remind participants that human activities are responsible for much of the movement of weeds.

  · with crop seed

  · equipment

  · irrigation systems

  · animals

- Dormance of seeds

  – a state of suspended development

  – a survival mechanism for weeds

  – makes control more difficult

  – types of dormancy:

    · innate: impermeable or mechanically resistant seed-coat; endogenous chemical inhibitors

    · induced: seeds would ordinarily germinate if planted under favourable conditions but if exposed to unfavourable conditions, become dormant and will not germinate even when conditions become favourable

· enforced: one or more environmental factors are unfavourable — moisture, temperature, oxygen

- Factors influencing weed distribution in a climatic zone

  – soil moisture

  – soil pH

  – similarity of crop and weed life cycle

  – similarity of crop and weed seed size

  – influence of human activities/management

□ *Discuss the concept that many weeds do not survive well except in a disturbed environment such as that of an annual crop. Examples: wild oats,* Amaranthus *spp.,* Chenopodium *spp.,* Setaria *spp.,* Echinochloa *spp.*

- Allelopathy

  – harmful effects of one plant on another through the production of chemical compounds

  – some authors include positive responses as well

## Weed interference

It has long been recognized that weeds interfere with crop plants. Interference has been divided into two aspects: allelopathy and competition.

## *Allelopathy*

- The production by one plant of substances that interfere with the germination, growth or development of another plant

  - exudates from roots

  - with rainfall, leachates from stems and leaves

  - toxins upon decomposition of plant parts, including roots, stems, leaves, rhizomes, stolons and tubers

## *Competition*

- Limiting-factor concept involves

  - competition with crops for nutrients, water, light and space

  - duration of competition

□ □ There is a need to determine which factor(s) are actually limiting in a given situation; this is dependent on the competitive ability of respective crops and weeds. Weeds often use resources more efficiently than crops.

- Factors of competition

  - nutrients — absolute amount available and period of availability/scarcity are important

  - water — plants more susceptible during germination, floral initiation, and grain filling; serious loss of moisture can occur in fallow period

  - light — vigorous, rapidly developing seedlings and tall plants have competitive advantage

  - often dramatic differences between plants of same species

– shade-tolerant species have an advantage

– competition for space, pollinating agents, oxygen, carbon dioxide and heat are difficult to demonstrate

***Generalizations***

- First plants to occupy a space have competitive advantage

- Weeds of similar growth habit as the crop are often more serious competitors than weeds of a dissimilar growth habit

- It is often said that the most serious competition usually occurs in the first one-third of a crop's life cycle. It is more correct to say that plants are most susceptible to competition when young, although serious competition occurs when one or more factors become limited.

Caution: Competition data are only an indication of losses under similar conditions. Temperature, rainfall, soil type, crop species and weed species will influence losses.

□ *Question*: How would you plan an experiment to determine a critical period of competition for an annual crop?

If a minimum acceptable yield of 70 percent of the weed-free yield is set, the crop should be weed-free between the twenty-seventh and fifty-second day after emergence. This is often referred to as the "critical period" of competition.

□ *Question*: How would you determine whether interference is caused by allelopathy or competition?

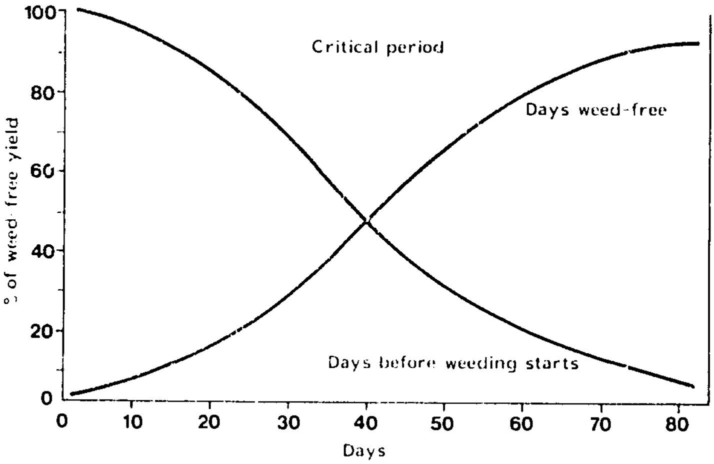
□ □ Emphasize that the critical period will change with changes in the environment (years).

**Treatment**

1. 0-10 weed-free days after emergence
2. 0-20 weed-free days after emergence
3. 0-30 weed-free days after emergence
4. 0-45 weed-free days after emergence
5. 0-60 weed-free days after emergence
6. 0-90 weed-free days after emergence
7. Weed-free
8. First weeding 10 days after emergence, then keep weed-free
9. First weeding 20 days after emergence, then keep weed-free
10. First weeding 30 days after emergence, then keep weed-free
11. First weeding 45 days after emergence, then keep weed-free
12. First weeding 60 days after emergence, then keep weed-free
13. First weeding 90 days after emergence, then keep weed-free
14. Control — unweeded

---

*Critical period of competition for an annual crop*



## Weed identification

For a national or regional training course on weed management, it is important to have participants collect and identify some local weeds. Correct identification makes possible a literature search for information on the biology of the species, which may be useful in determining a control programme. Knowledge of the distribution of a weed species allows prediction of its relationship to environmental conditions and enables its spread into new areas to be predicted and monitored.

The typical agriculturist should approach weed identification goals and practices realistically. Unless he or she has formal training in plant taxonomy or has an unusual interest in botany, a reasonable goal would be to learn to recognize those weeds common to local cropping systems.

☐ *Question:* Why is it important to identify weed species correctly?

The following steps should be useful in preparing for the weed identification segment of a weed management training course:

- Whenever possible, seek the services of a taxonomist familiar with local weeds

- Obtain some easy-to-use weed identification guides for your area; if these are not available, consider working with a local taxonomist to prepare one

- Obtain as complete a plant specimen as possible for screening out or identification

  – include underground parts, flowers, fruits, stems, and basal and upper leaves

  – the more complete the specimen, the better your chance of success will be

- While classical taxonomists depend on flower parts as primary identification criteria, a practising agriculturist must identify weeds before the flowering parts appear

- Learn to recognize distinctive identifying features such as leaf shape, surface texture, venation, perennial reproductive structures and distinctive odours. Even the pattern of growth in the field, season of germination and time of flowering offer clues for recognizing certain weed species.

# 3 Weed control

## Methods of weed control

Weed control is part of a more general problem: vegetation management, in which conditions are created that favour desirable plants while suppressing unwanted plants.

No single plant species can fully exploit the resources of a habitat. This is why any natural stand of vegetation, even a climax vegetation, is a mixture of species. In contrast, monoculture, which is practised in most developed countries, leaves "niches" of unutilized resources. The goal of vegetation management is to leave as few niches as possible; for example, by close planting, and disrupting available niches by hand weeding, cultivation, the use of herbicides, and so forth, so that plants cannot invade.

### *Important weed management concepts*

□ *Before considering various weed control methods, the instructor should mention three concepts important to weed management:*

• *Prevention* — preventing the entrance of new seeds or plant propagules into an area or preventing seed set on existing plants. Methods of prevention include:

- sanitation of non-crop areas on the farm
- quarantine of animals
- use of clean seed
- screening of irrigation water

– laws designed to prevent the seeds or propagules of certain plants from entering a country

- *Eradication* — eliminating all plants and plant parts of a single species from an area. This is very difficult on a large scale and probably uneconomical in most cases.

□ □ This is a good place to ask participants to suggest situations in which it might be justifiable to attempt the eradication of a species.

– a new weed with limited distribution

– a weed restricted to a limited area, that is, a single farm or field

– a weed so noxious as to justify this effort

- *Control (management)* — limiting weeds so that they do a minimum of harm. The degreee of management (control) depends on benefits/costs and resources available

***Physical control methods***

- Machine tillage

– effective on annual weeds

– applicable in extensive areas where access is not limited by topography or weather; if used systematically, can reduce seed supply in the soil

– special tillage practices include: delayed tillage — preparing seed-bed, waiting until weeds have germinated, tilling lightly, and seeding crop; blind tillage — planting crop and performing shallow tillage before crop emerges (most practical when weeds emerge well ahead of crop)

– perennial weeds may be controlled with tillage through:

*i) carbohydrate depletion* — when top growth is cut off, perennial plants draw upon root reserves to produce new top growth; maximum depletion of root reserves will occur if cultivation is done 10-15 days after emergence of new growth (this period may be longer if environmental conditions retard the growth rate); and

*ii) desiccation of rhizomes, tubers and roots* by leaving them exposed on the soil surface. This requires repeated tillage and, at best, will reduce weed population only to a tolerable level.

- Mowing

– effective on tall weeds, but not for low-growing weeds

– weed seeds can mature after being cut off

– often used to reduce competition in newly planted perennial crops that can recover from mowing; for example, forage grasses or legumes

- Hand pulling or hoeing/cutting

– labour-intensive

– free from costly/sophisticated machinery and chemicals

– often the most practical method for small farmers with limited resources or an abundance of hand labour

– some closely planted (seeded) or broadcast crops are difficult to hand weed without damage to crop

- Flooding

  – limited to areas where water is available and can be impounded

  – used in rice and taro and in special cases to control perennial weeds in non-crop periods

- Mulching

  – the use of plant parts, plastic, paper, sawdust or other materials can reduce germination and development of weeds while reducing erosion and conserving moisture

  – when crop residue is used as mulch, seeds from that crop may grow and create a problem

- Selective flaming

  – the crop must be larger than the weeds or protected by shields

  – requires a source of fuel and equipment

- Non-selective flaming

  – used in land clearing or for sanitation in non-crop situations

  – often destroys many weed seeds, but can stimulate germination of certain seeds

  – can lead to predominance of perennial species

  – also allows more soil erosion on slopes

### *Cultural control methods*

This includes any husbandry or management practice that enhances a crop's ability to compete with weeds. Cultural control is basically the art of managing vegetation; it is especially important with closely spaced crops like small-grain cereals.

□ □ This is a good point to ask participants for examples of cultural control.

- Crop interference (interference may include both competition and allelopathy)

  - selection of a competitive crop
  - selection of a competitive variety
  - manipulation of planting arrangement and density
  - allelopathic effects of certain crops
  - shift to a smother crop
  - multiple cropping

- Fertilizer placement
- Timing of planting
- Liming
- Irrigation and drainage
- Crop rotation

  - from spring-seeded to autumn-seeded crops (which breaks the life cycle of some weeds)
  - to crops planted in rows to allow cultivation or hand weeding

– to a different crop, which would permit the use of a different herbicide treatment

### *Other control methods*

- Biological control: the use of biotic organisms to control weeds; should be treated separately

- Chemical weed control: the use of organic and inorganic compounds to disrupt plant growth

- Integrated weed management: several weed control methods combined to increase effectiveness and efficiency

## Biological control of weeds

The influence of insects, mites, plant pathogens and other organisms on plant growth is a natural process and has existed since the origin of plants. For centuries, weed growth has been managed by birds, fish and grazing animals such as goats, sheep and cattle. This is biological control. Still, the conscious use of these biological agents for weed management is relatively recent.

### *Terminology*

- Monophagous — feeds on only one species

- Oligophagous — feeds on a few species

- Polyphagous -- feeds on many species

- Classical biological control — introduction of one or more organisms that are known to attack the weed in its native range and which are absent from the areas in which the weed problem exists

*Basic approach to classical biological control*

- Look at the distribution of the weed in your country

  – Is it serious enough to justify the expense?

  – Is it always considered a weed?

  – Are there already control agents in the area that could be helpful with some management?

- Go to the country where the weed came from to look for a natural enemy

- Determine whether the control agent could be a threat to other species

  – Check the geographical distribution of the weed and the organism in the country of origin. If the organism has a wider distribution than the weed, it may be attacking other plants.

  – Check the taxonomy of the weed. If it is closely related to a valuable species, be cautious.

  – Will the control agent feed on an economic species in a prolonged absence of the preferred weed species? (Starvation test)

- Bring the control agent to the new country

  – Make sure no other organisms come with it.

  – Free the organism of its own predators.

  – Release, manage and redistribute the agent as required.

### *Examples of successful biocontrol programmes*

- Prickly pear cactus (*Opuntia* spp.) infected 25 million hectares in Australia. *Cactoblastis cactorum* was the principal insect, but several others were also helpful; great improvement was achieved after five years.

- St Johnswort (*Hypericum perforatum*) infected many hectares of rangeland in northern California. *Chrysolina quadrigemina*, a beetle, has given good control.

- Skeleton weed (*Chondrilla juncea*) spread over 25 million hectares in Australia. Good control was achieved with *Puccinia chondrillina*, a fungus.

### *Characteristics of biological control*

- The cost of developing biocontrol agents is usually publicly funded. In contrast, herbicides are usually developed privately.

- Control is never complete and occurs in cycles

### *Advantages of biological control*

- No chemical residues or toxic hazard
- Host-specific
- Self-perpetuating once established
- May be less chance of the weed developing resistance
- Energy-efficient
- Effective in inaccessible areas
- Inexpensive after initial cost of development

### *Disadvantages of biological control*

- The behaviour of the control agent may change
- Usually neither rapid enough nor complete enough for cropland
- Generally limited to a selected species
- Irreversible after release
- Conflicts of interest may arise over the target weed

## Socio-economic considerations

In most developing countries there are two levels of agriculture, commercial and subsistence, often existing side by side. The same economic analysis is usually not relevant to both levels, and differences between the two are critical when evaluating weed control technologies.

Commercial farming is primarily concerned with operational efficiency to maximize net income. The major problem facing these farmers is adjusting to the effects of changing technology.

Subsistence farming, on the other hand, is characterized by relatively simple and stable technologies. The major problem for these farmers is obtaining new information and resources in order to break out of a poor (albeit efficient) production system and improve their economic position.

### *Characteristics of commercial farms*

- Large
- Capital-intensive
- Use modern technology

- Production goes to national and international markets
- May utilize a substantial amount of local labour on a seasonal basis

### *Characteristics of subsistence farming*

- Small
- Labour-intensive
- Use traditional technology
- Production is used on farm or traded locally
- Limited and expensive capital
- Uncertain markets
- High risk because of weather and pests
- Limited alternative employment
- Shortage of labour at critical periods
- Limited education

### *Weed control for subsistence farmers*

Subsistence farmers commonly expend about 40 to 60 percent of their labour on weed control before or after planting. The adoption of labour-saving methods may have a negative impact on the labour-force, and may also be resisted because farmers are reluctant to adopt a technology that carries added risk. As weed control systems may be highly site-specific, the direct transfer of technology is rarely successful.

The selection of agronomically, economically and socially acceptable weed control systems requires an understanding of the technical, economic and social realities of the area. The following steps should be followed in developing weed control alternatives.

- Identify the target farmer group
- Identify current agronomic practices and why they are used
- Study socio-economic conditions
- Test promising methods on farmers' fields using farmers' management
- Modify as needed
- Promote methods to target farmers
- Monitor adoption and success

This process requires a multidisciplinary team of agronomists, economists, extension agents and farmers. It must be kept in mind that people, not crops, are the target, and that an appropriate technology is a technology that is adopted.

□ □ Whenever possible, organizers should try to have an economist inform participants of the methods used to collect and analyse economic data.

The following are readings in economics of particular interest and help to agronomists, although too basic to be useful to agricultural economists on multidisciplinary development teams:

McCarl, B.A. *Economics of integrated pest management: an*
1981 *interpretive review of the literature.* Corvallis, Oregon, International Plant Protection Center. Special Report No. 636.

PERRIN, P.K. *From agronomic data to farmer recommendations:*
1976 *an economics training manual.* Mexico City, Centro Internacional de Mejoramiento de Maíz y Trigo. Information Bulletin No. 27.

REICHELDERFER, K.H., CARLSON, G.A. & NORTON, G.A.
1984 *Economic guidelines for crop pest control.* Rome, FAO. FAO Plant Production and Protection Paper No. 58.

SHANER, W.W., PHILIPP, P.F. & SCHMEHL, W.R., eds. *Farming*
*1982* *systems research and development: guidelines for developing countries.* Boulder, Colorado, Westview Press.

## Shifting weed populations

One of the dynamic phenomena occurring in natural ecosystems is the constant competition between plants to occupy the same area. With the passing of time, certain species tend to predominate as they win the struggle for space. The final species composition in a climax vegetation differs greatly from that which is present in the early years of the succession process following a major disturbance of an ecosystem. Agricultural systems represent highly disturbed ecosystems, and thus it is not surprising that frequent changes in species composition occur in farm fields. The purpose of this discussion is to examine factors affecting shifts in the balance among weed species.

### *Management practices affecting weed flora*

*Cropping practices*

- Types of crops
- Life cycles of crops and weeds
- Competitive ability of different crops

- Cropping patterns
  - monocrop
  - polycrop
  - spacing and density of crops

*Husbandry practices*

- Fertilization
- Liming and other special soil amendments
- Drainage
- Irrigation
- Time of planting

*Weed control methods*

Weeds exert a constant pressure to adapt to environmental conditions and invade unoccupied niches. No single method will control all weeds. The repeated use of one method permits a buildup of species not being controlled.

## *Development of resistance*

*Physiological resistance*

- True physiological resistance should be distinguished from selectivity (resistance) resulting from factors such as herbicide placement, differential wetting and the timing of application

- The genetic changes associated with true physiological resistance require many generations of repeated exposure of the same species to a herbicide. With herbicides, the development of physiological resistance is a very slow process, especially where only one or two annual applications are made.

*Buildup of non-susceptible species*

- Within a given weed flora, many species may not be susceptible to a herbicide

- Within a susceptible species, there may be a very low percentage of biotypes (strains) that are not susceptible

- Repeated application of the same herbicide results in a reduction of susceptible species and biotypes and an increase in non-susceptible ones until the latter predominate. This does not involve genetic changes and is not equivalent to the development of resistance.

*Prevention of the development of herbicide resistance and the buildup of non-susceptible species*

- Rotation of crops
- Rotation of weed control methods
- Rotation of herbicides
- Combination of herbicides
- Integration of weed control methods

# 4 Application of weed management technologies

## The safe use of pesticides

### *Toxicity and hazard*

Pesticides have the potential to benefit or harm humans and the environment. Their proper use or abuse determines end results. Two important concepts for this discussion are toxicity and hazard.

- *Hazard* — the chance or danger of harm
- *Toxicity* — how poisonous a compound is

Toxic compounds should be considered hazardous, but their careful handling can reduce the hazard. Conversely, even compounds of relatively low toxicity can be hazardous if handled unwisely.

### *Measurement of toxicity*

There are basic measures of toxicity.

- *Acute*— single oral exposure
- *Chronic*— sublethal dose repeated over time

### *$LD_{50}$*

$LD_{50}$ — the single dose that kills 50 percent of a group of test animals when taken orally. $LD_{50}$ is usually expressed as milligrams of pesticide per kilogram of body weight of the test animal; the lower the $LD_{50}$, the higher the toxicity.

> *Example* Calculate the dose that would be lethal in half the cases for a person weighing 70 kg, for one pesticide with $LD_{50} = 5$ and another pesticide with $LD_{50} = 5\ 000$.
> Theoretically, for a person weighing 70 kg, in the first case 0.35 g (5 mg/kg × 70 kg = 350 mg) would be fatal half the time, while in the latter case 350 g (5 000 mg/kg = 70 kg) would be fatal in half the cases.

Determination of $LD_{50}$'s is performed on test animals such as rats, mice, guinea-pigs and rabbits, not on humans. $LD_{50}$ values from test animals cannot be extrapolated to human beings. Humans might be more or less susceptible than the test animal, just as one species of animal usually has a different $LD_{50}$ value from another species. Within a given species, it is common to have a differential susceptibility between males and females, or for different ages. The physical condition of a person may also influence susceptibility. For these reasons, the $LD_{50}$ should be considered as a relative or comparative value.

*$LD_{50}$ should never be considered the "safe dose"* — it must be remembered that 50 percent of the population died at this level.

Other measures of toxicity

- *Dermal $LD_{50}$* — dermal exposure

- $LC_{50}$ — the concentration of a chemical in the air (inhalation toxicity) or water (aquatic toxicity) that will kill 50 percent of the organisms in a specific test situation

- *Sublethal exposure* to agricultural pesticides is more common than acute exposure

  – effects of repeated exposure to sublethal dosages over time are determined in long-term chronic feeding tests

– animals are carefully observed for signs of abnormality

– "no-effect" level is often reported as parts per million (ppm) of the pesticide in the feed at which no effect was detected after a known period of consumption

– histological examinations are performed to determine effects on the vital organs of a test animal

*Factors affecting hazard*

Route of exposure

- *Oral ingestion* frequently occurs when food products are contaminated by pesticides or pesticides are stored in food containers and mistakenly eaten. Oral ingestion is probably the least common form of accidental contamination to agricultural workers.

- *Dermal exposure* — spills or failure to protect the hands while mixing or preparing pesticides are common means of exposure for agricultural workers. This is probably the easiest route of exposure to guard against by creating proper awareness.

- *Inhalation* of dust, vapours and spray mists of pesticides is probably the most dangerous exposure method. Assimilation in the bloodstream from the lungs is highly probable. The general awareness of the potential for inhalation is probably lower than for the other methods, especially from vapours or spray mists.

Other factors influencing hazard

- Application methods
- Storage and handling facilities
- Persistence of the pesticide in the environment
- Frequency and extent of use

- Type of crop treated (i.e. a fibre or seed crop as opposed to an edible crop)

- Pesticides may also enter the body through the eyes. One of the resulting dangers is blindness.

*Safety precautions*

- Plan ahead — only as much pesticide as needed, thereby avoiding storage

  – storage increases the possibility of degradation and contamination of a product as well as exposure to humans, animals and the immediate environment

- Read labels — follow instructions carefully

- Move pesticides safely

  – never transport or store pesticides with food products

  – always move pesticides in a closed container

- Protective clothing. The minimum safety equipment should include:

  – rubber boots

  – long trousers

  – shirt

  – rubber gloves

  – respirator or a cloth covering the nose and mouth, and goggles for the eyes for pesticides that present special hazards

- To avoid exposure while applying pesticides never eat, drink or smoke

- Hygiene

  – wash hands and face thoroughly after spraying

  – wash clothes before wearing them again

- Avoid equipment accidents

  – check equipment for leaks, weak hoses, faulty connections and other defects

  – do not put the filler hose in the tank mix

  – avoid pouring or spilling pesticides near ditches, wells or other water sources

- Inform the equipment operator of the product being applied and its potential hazards

***Disposal***

- Try to avoid surplus. Calculate the amount needed accurately and buy only the amount needed.

- If excess pesticide remains in the sprayer, spray it in a safe place such as a grassy roadway or fallow field to avoid a high concentration of pesticide in a small area. Do not let animals graze the area until adequate time has elapsed.

- Rinse empty containers thoroughly. Triple rinse and always pour the rinse water into the spray tank.

- Dispose of empty containers

  – burn bags in a safe place where not prohibited by law

  – avoid inhaling smoke from burning bags

  – return empty metal and glass containers to distributor/manufacturer if this service is available

– if no hazardous material dump area is available, crush containers and bury in an area where the ground-water supply will not be contaminated

– although never a recommended practice, many farmers save useful containers to store and transport other substances, including water and milk. Such containers must be washed with extreme care to reduce possible contamination.

***Storage***

- Store pesticides in an area away from living quarters, animal pens and water supplies

- Keep pesticides in a locked storage area, out of the reach of children

- Never store pesticides with foods

- Avoid storing pesticides with seeds and fertilizers

- Always store pesticides in a closed container to reduce degradation and contamination

- Check periodically for leaks

- Place warning signs in the storage area

- Never store pesticides in empty food containers

## Chemical control of weeds

Chemical control is not *the* control, nor should it frequently be used alone: integration with other control methods assures a more effective result. Socio-economic and agronomic conditions will determine which methods are combined.

- ☐ *You may want to discuss briefly the differences between large farms and small farms, or between commercial and subsistence operations. This will also be covered later.*

- ☐ *Ask course participants to list the advantages and disadvantages of chemical weed control.*

***Possible advantages of herbicides***

- Speed of control — can be used on extensive areas
- Less drudgery than manual control
- Control in critical period when the weather does not allow other methods to be used
- Selective control
- Control of special weed problems
- Control in closely spaced (closed) crops
- Reduced erosion with less cultivation
- Mixtures permit broad spectrum control
- Possible economy

***Possible disadvantages of herbicides***

- Certain technical skill required
- Special equipment required
- Potential for crop injury both within and outside the target area
- May fail to kill the weeds

- Not totally safe for animals or humans (potential for environmental contamination)

- Weeds may develop resistance

- May create reliance on an imported product

- Secondary weeds may become a primary problem

- Cost: limited power and credit make it difficult for small-scale farmers to buy herbicides

- Polycrops — selectivity a problem when several crops are present

### *Herbicide identification*

☐ *Herbicides have several possible "identities". You may want to discuss the different identities that a person has: a full given name; only one or two names of the full name; a nickname; a social security/carnet number, etc.*

- Herbicides have four possible identities:

  – a chemical formula, following the basic rules of chemical nomenclature

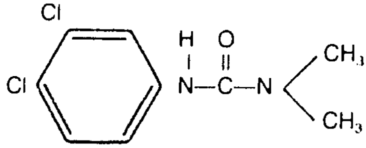
  – a common name which begins with a small letter. Common names are assigned by organizations such as the British Standards Institution or the Weed Science Society of America.

  – a trade name which begins with a capital letter. The trade name is the property of the manufacturer.

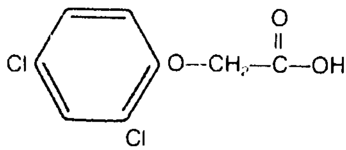
  – a chemical structure

- Each identification is illustrated in the following examples:

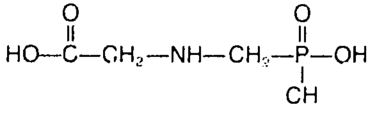
- chemical formula — 3-(3,4-dichlorophenyl)-1,1-dimethylurea
- common name — diuron
- trade names — Diurex, Karmex, Telvar
- chemical structure:




- chemical formula — (2,4-dichlorophenyl)acetic acid
- common name — 2,4-D
- trade names — Dacamine, Esteron, Formula 40, Hendonal, Trinoxal
- chemical structure:




- chemical formula — N-(Phosphonomethyl)glycine
- common name — glyphosate
- trade name — Round-up
- chemical structure:



### *Herbicide classification*

There are different groupings of herbicides which allow us to suggest or predict how they might be used. The most common systems are:

- Time of application

| *Period* | *Crop* | *Weeds* | *Examples* |
|---|---|---|---|
| Pre-plant | Pre-plant | Post- | Glyphosate or paraquat alone or mixed with soil-applied herbicides in No-Till |
| Pre-plant incorporated | Pre- | Pre- | EPTC in maize; trifluralin in cotton |
| Pre-emergence | Pre- | Pre- | Atrazine in maize; diuron in cotton |
| | Pre- | Post- | Atrazine in maize |
| Post-emergence | Pre- | Post- | Paraquat, No-Till |
| | Post- | Post- | Propanil in rice; 2,4-D in wheat |
| | Post- | Pre- | DCPA, transplanted tomatoes |
| Post-directed | Post- | Post- | MSMA in cotton; paraquat in maize; 2,4-D in coffee |
| At emergence | With emergence of first leaves | Pre- or early post | DNBP in potatoes, groundnuts, beans |

- Selective vs. non-selective. Selectivity is relative — it depends on the herbicide rate and the state of plant growth.

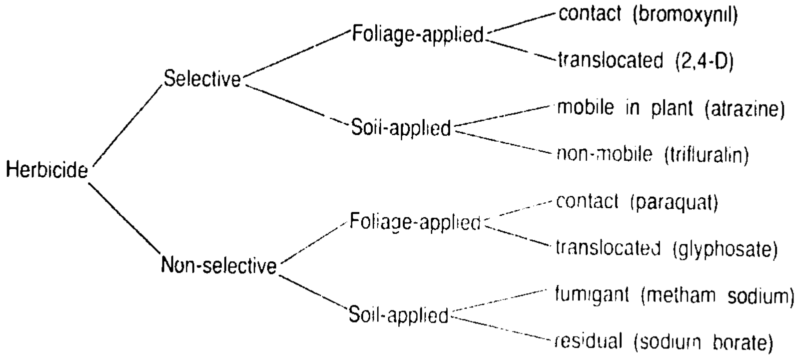
- Foliage-acting vs. soil-acting
  - some herbicides fall in only one category
  - some are effective on both leaves and soil
- Contact vs. translocated
- Mode of action — herbicides interfere with one or more of the physiological processes of a plant. Many of these processes have been identified, although the exact mechanism may not be known. Some of the identified modes of action include:
  - acting as mitotic poisons
  - regulating growth
  - inhibiting photosynthesis
  - inhibiting oxidative phosphorylation
  - inhibiting shoots of germinating seedlings
  - inhibiting roots of germinating seedlings
  - inhibiting chlorophyll
  - inhibiting protein synthesis/metabolism
  - increasing cell wall permeability
- Classification by herbicide families (chemical groups)
  - triazines
  - substituted ureas
  - phenoxy compounds
  - dinotroanilines

– carbamates

– dinitrophenols

– bipyridylium

- Classification by use:




## Principles of herbicide selectivity

Selectivity is the result of a herbicide reaching and disrupting the vital functions in one plant (the weed), but not in another (the crop). Selectivity is relative: the definition could include "under certain conditions and at certain rates". In many cases, the selective use of a herbicide is the result of a combination of two or more types of selectivity.

### *How herbicides work*

For a herbicide to be toxic to a plant, it must:

– make contact with its target (foliage or roots)

– penetrate the plant

– move to the site of action within the plant

– exercise a toxic effect upon the plant's vital process

An understanding of these occurrences enables one to manage herbicides to achieve selectivity.

## *Application of herbicides*

- Physical/mechanical (contact with the plant)

  – by directing sprays, or using shields, contact with the crop can be avoided and herbicides that are normally toxic to a crop can be used

  – *herbicide placement*: the rooting depth of a plant may be the basis of selectivity. Certain herbicides stay in the top layer of soil; crops can be planted deeper than the herbicide layer in order to avoid uptake by roots. The roots of perennial crops stay safely below the herbicide layer allowing annual weeds to be controlled.

  – *the timing of a herbicide application*: certain herbicides can be sprayed on weeds before the emergence of the slower germinating crop. Herbicides may be sprayed during a dormant period of the crop to avoid injury. During certain stages of development, plants will tolerate herbicides that are toxic during other growth phases. Timing the herbicide application to coincide with a "tolerant phase" permits selective use.

> *Example* Wheat will suffer abnormal growth if 2,4-D is applied during the period from germination to the four-leaf stage and from jointing through flowering. But during late tillering, and from the soft dough stage of grain through maturity, wheat is relatively tolerant to 2,4-D. Susceptibility is greatest during periods of most rapid meristematic development and applications must be avoided in these periods.

*Penetration of the plant*

- Morphology and anatomy of plant

  – position, size and shape of the leaves affect the retention of the herbicide, hence the opportunity for penetration into the plant

  – broad, flat leaves retain more herbicide than narrow erect leaves

☐ *Raise question about nature and function of cuticle in herbicide penetration.*

☐ ☐ Here is a good place to ask participants to discuss the morphological differences between monocots and dicots and how they affect the retention of a spray solution.

- Nature of leaf surface

  – the thickness of the cuticle and the degree of pubescence or roughness (corrugation) of the leaf surface influence penetration of the herbicide into the plant

  – a waxy or highly corrugated surface or one with extensive pubescence will reduce contact between the herbicide and the leaf surface, resulting in less or slower penetration

- Location of meristematic tissue

  – growing points (meristematic tissue) above ground may be more susceptible to herbicides than meristems at ground level or under the soil surface

  – perennial grasses have surface crowns or subsurface meristems of roots, rhizomes and tubers, and are thus better protected than annual grasses which have meristems at the soil surface

– meristematic tissue in broad-leaved plants tends to be more exposed than in grasses. The cambium layer and the dormant buds found in the stems of many broad-leaved species add to their susceptibility in many cases.

*Movement of the plant*

- Some herbicides move within the plant only in the xylem and others move only in the phloem

- A limited number of herbicides move in both tissues

- While the system in which a herbicide moves in a plant may determine the difference between sensitive and tolerant plants, the user cannot control it

- Manipulation is limited to applying the herbicide at the correct point, i.e. to the foliage or the soil to obtain the desired effect. For example, some hormonal herbicides will not control certain woody species when applied to the foliage but are toxic when applied to the root system.

*Toxicity and selectivity*

- In some cases, a herbicide molecule will be changed to a non-phytotoxic form in a tolerant plant (deactivated). Susceptible species do not have this ability.

- The user has little control over physiological and biochemical selectivity

- Conditions that place the plant under stress may interfere with these processes. Thus, it is advisable not to apply herbicides when environmental conditions are extreme.

- Interactions between certain herbicides and other pesticides may interfere with selectivity in a plant and result in toxicity to the crop

*Example* Propanil is commonly used to control weeds in rice; however, if certain carbamate or organophosphate insecticides are applied up to ten days before or after the application of propanil, the rice plant cannot deactivate the propanil and severe phytotoxicity results.

- Many economic plants have cultivars that are more or less sensitive to certain herbicides

☐ *Repeat*: Selectivity is relative. *Some types of selectivity can be overcome by increasing herbicide rates and by changes in environmental conditions.*

### *Environmental factors affecting herbicide selectivity*

- Temperature

  – within certain limits, absorption, translocation and physiological-biochemical processes increase as temperature increases

  – when selectivity depends on differential absorption or translocation, it can be altered at temperature extremes. For example, linuron can be used in wheat in temperate climates but is toxic to wheat in tropical conditions.

  – if propanil is applied to rice when the air temperature is above 38°C, phytotoxicity may occur

- Relative humidity — can influence herbicide absorption by affecting stomatal openings and the turgidity of the leaf

  – with high relative humidity, stomates are open and the leaf cells are more expanded causing minute openings in the cuticle that permit increased penetration of herbicides into the leaf. In some cases, the plant will absorb a herbicide at a faster rate than it can deactivate it, reducing selectivity.

– evaporation of the herbicide from the leaf surface is slower at a higher relative humidity, thus increasing the time available to penetrate into the plant

– relative humidity can also influence cuticle development. Under conditions of low relative humidity, plants have a thicker cuticle than under high humidity.

- Soil moisture — can affect selectivity by influencing the amount of herbicide in the soil solution and the depth of herbicide movement in the soil profile

  – high soil moisture can result in more herbicide in the soil solution and increased uptake

  – excess soil moisture may leach herbicides into the crop root zone, resulting in toxicity if the basis of selectivity is the difference between herbicide placement and rooting depth

  – leaching is more acute with herbicides having higher solubility or a higher leaching index. These factors are determined by the molecular configuration of the herbicide and are beyond the user's control. Nevertheless, a herbicide may be chosen according to its solubility or leaching properties and expected moisture regime in order to maximize efficiency.

### *Surfactants*

- Surfactants are chemicals that modify the relationship between the surfaces of two liquids or a liquid and a solid, facilitating and enhancing the emulsifying, dispersing, wetting, spreading, sticking and penetrating properties of liquids

- Surfactants can increase the retention and penetration of herbicides on and into plants

- The use of surfactants with foliage-applied herbicides when not recommended can result in a loss of selectivity

## Herbicide formulations

This topic is best presented as a demonstration. If samples of the various formulations can be acquired along with a few glass beakers and some water, it can be an interesting and informative presentation.

### *Formulation for practical use*

Formulation means preparing a technical-grade herbicide for practical use. A technical-grade herbicide is the pure chemical, either a liquid or solid, soluble or insoluble in water or various organic solvents. "Practical use" has several meanings. Since a relatively small quantity of herbicide must be spread evenly over a given area, some method of distribution is required. Water is the normal diluent, and most herbicides are formulated to be compatible with water. A few formulations are intended to be applied dry; the diluent may be an inert material such as finely ground clay.

The formulation chemist considers many things in deciding how to formulate a herbicide:

- The chemical and physical properties of the pesticide
  - solubility in various solvents, including water
  - volatility
- Geographical area of use
  - the customs of uses in various parts of the world may dictate how a herbicide is formulated; for instance, Asian rice farmers prefer a granular formulation
- Reliability and safety
  - shelf-life

- inflammability
- toxicity

- Economics
  - cost of materials
  - cost of containers
  - relative shipping costs: formulations with lower percentages of active ingredients tend to be more expensive because more total weight must be shipped to move the same amount of active ingredient

***Formulations to be sprayed in water***

- Choice will depend on the solubility of the technical herbicide

- To be soluble enough, the solution must not exceed 12 percent (120 000 ppm), which is equal to .1198 kg/l (1 lb/US gallon)

***Water-soluble concentrates***

- The active ingredient can be dissolved readily in water to form a true solution

- The manufacturer can dissolve the material in water and sell the product as a concentrate for further dilution by the user

- The manufacturer may also choose to sell a water-soluble herbicide as a dry powder for mixing with water by the user

- Adjuvants may be added to improve effectiveness
  - wetting agents improve retention and penetration
  - sequestering agents prevent precipitation in hard water

- Important characteristics of water-soluble concentrate formulations:

  – relatively low cost

  – no agitation required in sprayer

  – reduced hazard to user because it can be easily washed off the skin

  – may react with hard water

  – active ingredient may not enter plant readily, a desirable trait if it is a mechanism of selectivity, or undesirable if it reduces control of certain weeds

  – chemicals can be readily leached through the soil by water, an advantage when applying a herbicide to control deep-rooted perennials

  – excess leaching can be a disadvantage if it results in short residual control, ineffective performance or crop injury

*Emulsifiable concentrates*

- The active ingredient cannot be dissolved in water; however, it is soluble in a suitable non-polar organic solvent

- The manufacturer dissolves the herbicide in the organic solvent and adds an emulsifying agent (a surfactant)

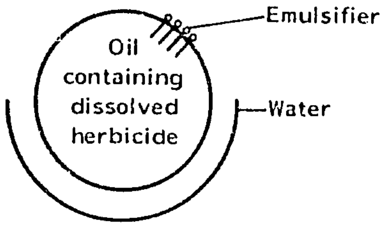
- Emulsifiable concentrate is mixed with water by the user to form an emulsion

- Characteristics of emulsifiable concentrate formulations:

  – relatively high cost because the solvent is expensive

  – relatively more hazardous to user because oily material is not as easily washed off the skin

*Example* An example of a common emulsion is oil suspended in water. Usually, when oil is mixed in water, the oil coalesces to form large droplets and the oil and water separate rapidly. When a surfactant is added, it forms a more stable emulsion. Each surfactant molecule has two ends, a lipophilic end that extends inwards, attaching itself to the oil droplet, and a hydrophilic end that extends outwards into the water, repelling adjoining oil droplets (see Figure). Thus, a stable emulsion with thousands of tiny globules suspended in the water is formed. The oil droplets will remain suspended in the water as long as they are kept very small. Some agitation may be required to keep the droplets in suspension.




– penetrates the waxy surface of leaves more effectively than other formulations

– less likely to be washed off foliage by rain or irrigation

– chemical not so readily leached through the soil because of low water solubility

*Wettable powders*

- Sometimes a technical herbicide is not soluble enough in water nor in an organic solvent, but being able to spray it in water is desirable

- The herbicide can be very finely ground and formulated as a wettable powder, a powder that will readily form a suspension in water

- A wettable powder is formulated by impregnating a technical pesticide on an inert material such as clay

- A typical 50 percent wettable powder may contain 46 percent clay, 2 percent wetting agent, 2 percent dispersing agent, and 50 percent technical herbicide

  – the wetting agent helps wet the powder so that it will dissolve rather than float on the surface

  – the dispersing agent aids in spreading the particles throughout the water

- Important characteristics of wettable powder formulations:

  – relatively low cost because they weigh less than liquid formulations and require less expensive packages

  – agitation of the spray tank required to keep particles in suspension

  – dusty

  – abrasive to pumps and nozzle tips

  – generally less foliar activity than other sprayable formulations

  – often require rainfall, irrigation or mechanical incorporation to move them into the soil

*Flowable formulations*

- A flowable formulation is a concentrate of a solid herbicide suspended in a liquid, a kind of slurry pre-packaged for addition to spray tanks

- Important characteristics of flowable formulations are the same as those of wettable powders, with the advantage that flowable formulations are not dusty and can be measured rather than weighed

*Dry flowable formulations or dispersable granules*

- Wettable powders that have been formed into small granules

- When added to water, the granules break up and disperse as with a wettable powder

- A dry flowable or dispersable granule formulation has the same advantages as a normal flowable formulation:

  - because powder has been pressed into granules, there is little or no dust and material can be easily poured and measured

  - percentage of active ingredient in granules is high (80-90 percent) in contrast with dry granule formulations

***Formulations to be applied dry***

*Granules*

- Prepared by impregnating the technical herbicide on inert particles, such as clays

- Granular formulations contain from 2-20 percent concentrations of active ingredient because the inert clay is used as the diluent rather than water

- Characteristics of granule formulations

  - may be applied with less expensive equipment than sprays

  - penetrate a plant canopy and reach the soil easily

  - may release the herbicide gradually over a period of time

  - less drift hazard

  - relatively higher cost

– more chance of poor distribution on the soil since granules may roll or be blown into furrows or other depressions

*Pellets, tablets, balls*

- Both water-soluble and non-water-soluble herbicides may be formulated into larger-sized pellets for special needs such as spot treatment

## Adjuvants for herbicides

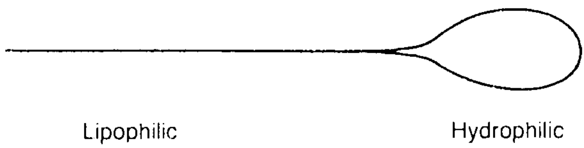
An adjuvant can be defined as a substance added to a prescription to aid in the operation of the main ingredient. Possible reasons for the addition of adjuvants to the spray tank of pesticides include

- Improved wetting
- Reduced evaporation
- Increased penetration
- Improved translocation
- Extended weatherability
- Slowed release
- Adjusted pH
- Deposition
- Compatibility aid
- Retarded drift
- Odour inhibition

A few of the types of adjuvants that are of particular importance to herbicide users are discussed.

### *Surfactants*

The word "surfactant" is an acronym derived from "surface active agent". Surfactant molecules are sort of double-ended, composed of a lipophilic portion and a hydrophilic portion (see Figure). The lipophilic portion is usually made of long-chain hydrocarbons or benzene-type ring structures which have low water solubility but high oil solubility. The hydrophilic end has a strong affinity for water.




There are three primary classes of surfactants, determined by the chemical structure of the molecule's hydrophilic portion:

- *Anionic* — ionizes in water to form a negatively charged substance; may react with contaminants, including minerals in "hard" water, in spray solution

- *Cationic* — ionizes in water to form a positively charged substance; may react with contaminants in spray solution

- *Non-ionic* — most commonly used agricultural surfactants are non-ionic; easy to use, unaffected by hard water

Specific surfactants can be used in many ways:

- Wetting agents

- Dispersing agents

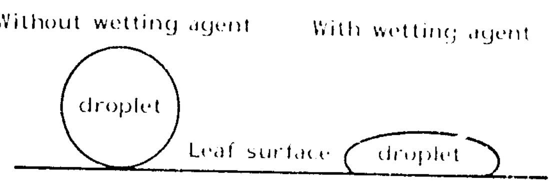
- Emulsifiers

- Foaming agents

- Detergents

### *Wetting agents*

Wetting agents are substances added to herbicide sprays to increase the spread of spray droplets over the surface of foliage. They work by reducing the surface tension of droplets (see Figure).




The total effect of a wetting agent is not well understood. It is known that a maximum reduction of surface tension is achieved with wetting agent concentrations of less than 0.1 percent. This means that increasing the rate of surfactant will not cause the spray droplet to spread out further. But it is also known that the uptake and effectiveness of many herbicides continue to increase as the wetting agent concentration increases above 0.1 percent. The implication is that wetting agents improve the uptake of a herbicide in other ways besides reducing the surface tension of the droplet.

### *Oils*

Oils have been used in herbicide sprays for many years. Oils are adjuvants but not surfactants. Oils can be divided into three types:

- Non-selective phytotoxic; diesel fuel, for example

  – heavy oils with a high degree of unsaturation (many double and triple bonds)

– generally added to knockdown-type herbicides for roadside spraying, canal and ditch-bank spraying, etc.

- Selective phytotoxic

  – oils that are not actually adjuvants because they may be sprayed directly without mixing with water or without combining with a herbicide

  – intermediate viscosity

  – used mostly for control of broad-leaved weeds in certain crops, such as the carrot family. The carrot family is apparently better able to withstand the effects of oil on membrane systems than most weeds, so the crop is not harmed, while the weeds are.

- Phytobland oil (sometimes called maize oils or spray oils)

  – light oils that are nearly saturated

  – not phytotoxic by themselves but often added to herbicides that need help in penetrating plant leaves

  – a major use has been in mixtures with atrazine for post-emergence application in maize

## Pesticide mixtures

Significant advantages often develop from mixing agrochemicals for simultaneous application:

- Saves time

- Reduces application costs

- Reduces soil compaction with fewer passes over a field

Mixing herbicides may have additional benefits:

- Broader spectrum of weeds controlled
- May reduce application rates of each herbicide
- Prevents shifts in weed populations
- May have a synergistic effect

***Potential problems with pesticide mixtures***

Users need to be aware of problems that may occur when pesticides are mixed:

- Reduced tolerance
- Reduced effectiveness

*Causes of incompatibility*

- Physical incompatibility may result in he flocculation of suspensions, separation of emulsions or adsorption of the toxicant of one pesticide on the diluent of the other
- Chemical reactions may occur among various components of the products being mixed
- Reaction among the surfactants (wetting agent, emulsifier, compatibility agent) in the various pesticides

***How to prevent problems with pesticide mixtures***

- Read the label. Certain mixtures may already have been shown to be compatible or non-compatible.
- Consult a pesticide compatibility chart. Compatibility charts

are updated and published each year by, among others: Meister Publishing Co., Willoughby, Ohio 44094, USA.

- Ask your chemical supplier

- When mixing a wettable powder with other formulations, always add wettable powder to the water first

  – if an emulsifiable concentrate is added first, its oil solvent will coat the wettable powder particles that are added later

  – this prevents a uniform suspension and causes flocculation of the wettable powder

  – an emulsifiable concentrate should be added to the tank after the wettable powder is in proper suspension. Water soluble concentrates should be added last.

- If there is any doubt about compatibility, the planned mixture should be tested in advance on a small scale

  – pesticides to be combined should be mixed in small glass containers at the same ratios to be used in the field

  – allow to stand for a few minutes and observe results

  – good agitation in the sprayer will help prevent problems

***Biological incompatibility***

Another problem of mixtures occurs not in the sprayer, but in the plants. There are two major types of biological incompatibility:

- The second component of a herbicide mixture may break down a selectivity mechanism in a crop, damaging the crop together with the weeds. This happens in several cases when insecticides and herbicides are sprayed together.

- There are also examples of reduced weed control from one of the components of a mixture. For example, when the new "double ring" grass killers are mixed with phenoxy herbicides, the control of broad-leaved weeds by the phenoxies is reduced.

## Herbicide application equipment

Herbicide application equipment ensures a uniform distribution of an exact quantity of pesticide in a given area and saves the farmer time and effort.

### *Types of applicators*

*Non-pressurized*

- Water can
- Duster
- Granular applicator
- Spinning-disc applicator
  - recognized for uniform droplet size
  - uses lower volume than most hydraulic applicators
- Direct-contact applicator
  - deposits herbicide through direct contact with the target plant; includes rollers, wicks and wipers

*Pressurized*

- Hydraulic — uses liquid (usually water) to distribute herbicide in target area

- manually operated
- motorized
- ground-driven

- Air
  - uses air current to distribute herbicide in target area
  - usually motorized
  - often called "foggers" but distinct from thermal foggers
  - rarely used for herbicide application

□ □ A knapsack sprayer should be available during this session. It is also helpful to have samples of other sprayers to demonstrate.

### *Spinning-disc applicator*

In this type of applicator, an electric or air-powered serrated disc produces ligaments of liquid that break up in droplets. Its chief characteristics are:

- Highly uniform droplet
- Speed of rotation and configuration of disc determine droplet size
- Current hand-held models are usually quite fragile
- Difficult to calibrate
- Difficult to see spray being applied, leading to concern about operator safety

*Source of power*

- Electricity

  – runs on two to eight 1.5-volt "flashlight" dry-cell batteries or one larger dry-cell battery

  – battery life and maintenance present problems

  – solar collector batteries should reduce battery replacement problems and costs

- Air

  – recently introduced models use a manually operated air pump

  – this unit, similar to a knapsack sprayer in appearance, may overcome battery replacement costs and erratic application costs

***Direct-contact applicator***

- Limited to systemic herbicides

- Especially useful for applying herbicides in areas where spray drift poses a danger

- Allows selective use of non-selective herbicides

***Hydraulic applicator***

The following are common components of hydraulic applicators:

- Tank — transports spray solution

- Agitator — keeps tank contents evenly mixed

– mechanical or hydraulic essential with large tanks

– advisable with smaller sprayers as well

- Pump — pressurizes the system, be it manual, motorized or ground-driven

- Pressure gauge

  – especially important on motorized equipment or in research work

- Pressure regulator

  – extremely important on motorized sprayers to avoid excessive pressure that could cause a rupture

- Hose — conducts spray mix from tank to boom, wand or nozzle

  – in-line primary screen/filter advisable

- Boom or wand — carries nozzles and helps convey liquid

- Nozzle — atomizes liquid for uniform coverage of target area

  – nozzle body

  – filter screen — non-drip filter advisable

  – nozzle tip — determines droplet size and spray pattern

  – nozzle cap — secures nozzle tip to body

*Types of nozzle tip*

- Flat fan tip

  – tapered pattern

- designed to be set on a boom so spray patterns overlap
- many sizes and angles available

- Even, flat fan tip
  - uniform pattern
  - designed for band application
  - many sizes and angles available

- Flood jet or impact tip
  - wide angle
  - operates at low pressure
  - droplet distribution less uniform than for flat fan type
  - less drift in windy conditions than with other nozzles

- Cone tip
  - cone-shaped pattern
  - used at higher pressures than the other types
  - produces small droplets
  - used for insecticides and fungicides

***Maintenance of applicators***

- Hydraulic and spinning-disc applicators need more maintenance than direct-contact applicators

- Chemical residues left in any applicator present a threat to the next crop sprayed

– to remove hormonal herbicide residues, fill the applicator with a 1 percent ammonia solution (found in several household cleaners), let stand overnight and, the next day, rinse three times with water

- Oxidation and corrosion commonly occur when sprayers are not properly washed after use

- Leaky hoses and faulty connections are common problems that should be checked often

- Plugged nozzle tips and screens result in non-uniform application

- Plugged nozzle tips should never be cleaned with hard objects

## Sprayer calibration

The accurate application of herbicides is so important and so often misunderstood that considerable time should be allotted to this subject. Both class-room and outdoor activities should be used.

Calibration involves determining or adjusting a sprayer's output to facilitate uniform distribution of an exact quantity of chemical in a given area. Excessive herbicide can kill the crop, cost extra money or leave undesirable residues in the soil. Too little herbicide, on the other hand, results in poor weed control.

### *Requirements for sprayer calibration*

☐ *This topic should be presented first in the class-room and then repeated in the field at the start of the calibration exercise.*

In order to calibrate a sprayer, one must be familiar with how it works. Beyond this, it is important to understand the factors that regulate sprayer output:

- Nozzle orifice size

  – there is a direct relationship between orifice size and output: the larger the orifice, the greater the output

- Speed

  – an inverse relationship exists between travel speed and sprayer output. For example, if speed is doubled, output is reduced 50 percent.

- Pressure

  – relative change in output is proportional to the square root of relative change in pressure at the nozzle. For example, in order to double output, pressure must be increased nearly fourfold.

### *Calibrating a motorized sprayer*

The objective of calibration is to determine the output of the sprayer, measured in litres per hectare. The correct procedure is as follows:

- Determine that the sprayer is functioning properly

  – there are no leaks

  – the sprayer is clean

  – the nozzles are uniform

  – the pressure is correct

  – the speed is set to the level desired

  – the boom height is correct

- Add water to the sprayer tank and mark the water level

- Spray a measured area at the speed and pressure desired

  – the area should be large enough to allow accurate measurement

  – ideally the procedure should be performed in the field to be sprayed or in an area with similar conditions to avoid changes in speed

- Record the amount of time required to spray the area

- Return sprayer to the same spot where the water level was first determined

- Measure the exact amount of water required to refill the sprayer to its original level

- To cross-check this amount, operate the sprayer in a stationary position at the same pressure for the same amount of time required to cover the measured area, and then collect and measure the output from two or more nozzles

- Multiply the average amount collected by the number of nozzles in the boom (as applicable)

□ □ The second method should be more accurate because it does not rely on the sprayer being placed in the same spot to measure the water level, especially when a large tank is used.

- Calculate the output in l/ha with the following formula:

$$\frac{\text{Water used in litres} \times 10\,000 \text{ m}^2}{\text{Area sprayed in m}^2} = \text{l/ha}$$

*Example:*

Test area = 400 m²
Water used = 6 l

$$\frac{6 \text{ l} \times 10\,000 \text{ m}^2}{400 \text{ m}^2} = 150 \text{ l/ha}$$

## *Calibrating a knapsack sprayer*

The knapsack sprayer is the most universal tool for applying herbicides in developing countries. It is also a very convenient sprayer for teaching calibration in a training course and for field research with herbicides. Because most knapsack sprayers do not pump out all of the liquid placed in them, the calibration and calculations are slightly different from those for motorized sprayers.

☐ *Participants should be split into groups and asked to go through the following steps to become familiar with the operation of a sprayer and the calculations necessary for accurate application.*

- Assemble the sprayer
- Add water and check for leaks and proper operation
- Practise spraying with water until everyone is comfortable with the operation of the sprayer
- Determine the amount of water that cannot be sprayed out:
  - add a measured amount of water to the sprayer
  - spray into a container of water with the nozzle held under the water surface
  - stop when large bubbles appear, which indicates that air is being pumped
  - measure the amount of water sprayed and subtract from the amount put in sprayer
- Add a measured amount of water (2-4 l) to the completely empty sprayer
- At a comfortable walking speed and pumping rhythm, spray a measured area

- Measure the water remaining in the sprayer (or the amount needed to refill it to the original level) and calculate the output in litres per hectare using the same formula as shown for the motorized field sprayer:

$$\frac{\text{Water used in litres} \times 10\,000 \text{ m}^2}{\text{Area sprayed in m}^2} = \text{l/ha}$$

*Example*

Area sprayed = 200 m²
Water used = 3 l

$$\frac{3 \text{ l} \times 10\,000 \text{ m}^2}{200 \text{ m}^2} = 150 \text{ l/ha}$$

## Herbicide calculations

□ *Following the sprayer calibration exercise, it is time to introduce calculations needed to arrive at the correct amount of water and herbicide to put in the sprayer. Many practice problems are necessary to be sure participants understand this process.*

Follow this procedure to calculate the correct mix of water and herbicide to put in the sprayer:

- Determine output per hectare using the formula:

$$\frac{\text{Water used} \times 10\,000 \text{ m}^2}{\text{Area sprayed}} = \text{l/ha}$$

- Determine the amount of active ingredient of herbicide needed to treat 1 hectare

- Determine the size of the area to be sprayed

- Calculate the amount of water needed to spray the desired area, as follows:

$$\frac{m^2 \text{ to be sprayed} \times \text{output in l/ha}}{m^2 \text{ per hectare}} = \text{litres required}$$

*Example*

Area sprayed = 100 $m^2$
Water used = 1.5 l

Thus output is equal to $\frac{1.5 \text{ l} \times 10\,000 \text{ m}^2}{100 \text{ m}^2} = 150$ l/ha

*Example*

Area to be treated = 4 plots of 50 $m^2$ each = 200 $m^2$
Output = 150 l/ha

Thus, water needed is equal to $\frac{200 \text{ m}^2 \times 150 \text{ l/ha}}{10\,000 \text{ m}^2\text{/ha}} = 3$ l

However, most knapsack sprayers do not pump out all the liquid in the tank, pump and pressure chamber. To determine the amount of water that must be added to allow for this and for minor errors, it is necessary to account for:

*a*) the amount needed to spray plots
*b*) the amount that is not pumped out
*c*) a margin for safety

*Example*

*a* = 3 000 ml (from previous example)
*b* = 450 ml (determined for each sprayer)
*c* = 200 ml (determined for each situation)

3 650 ml = Total amount of water needed for spray job

Now the amount of commercial produce (CP) needed for the above quantity of water can be calculated as follows:

$$CP = \frac{\text{Total water in litres}}{\text{Calibrated l/ha}} \times \frac{\text{Desired rate of herbicide}}{\text{Percent active ingredient expressed as a decimal}}$$

*Example* Assume we want to apply the equivalent of 2.0 kg active ingredient/ha of a product containing 80 percent active ingredient:

Thus, $$\frac{3.65\ \text{l}}{150\ \text{l/ha}} \times \frac{2\ \text{kg}}{.80} = .0608\ \text{kg, or } 60.8\ \text{g}$$

This means that 60.8 g of the commercial product would be added to 3.65 l of water to spray four plots of 50 $m^2$ each. When finished, 650 ml of the water-herbicide mixture would be left in the sprayer if spraying was equal to the calibrated amount. The amount of liquid remaining in the sprayer can be measured after spraying in order to verify accuracy.

## Factors affecting soil-applied herbicides

This is a very important topic if the weed management course includes a discussion of herbicides as a weed control tool. An understanding of these factors is essential if participants are to know how herbicides react in the soil environment.

Many herbicides are applied to the soil for uptake by the roots or by the emerging shoots of weeds. Roots are generally more effective than leaves at taking up herbicides; however, because of events taking place after application, soil-applied herbicides are not always available in sufficient quantities to kill the weeds. The major factor determining the effectiveness of a soil-applied herbicide is its availability to the weeds: the herbicide must be in the right place, at a high enough concentration, and for sufficient time, to achieve weed kill.

### *Soil components*

□ □ This is a good place to ask participants to list the components of soil.

- Minerals in the form of sand, silt, clay

- Gas in the form of nitrogen, oxygen, carbon dioxide, etc.

- Nutrients C, H, O, N, P, K, Ca, Fe, S, Cl, Mg, Mn, B, Zn, Mo and Cu

- Micro-organisms

- Insects, worms, animals, etc. (micro-organisms)

- Organic matter

  – partially decomposed and original tissue of roots and tops of higher plants and remains of fungi, bacteria, earthworms, rodents, etc.

  – humus — the decomposed residues of the above

- Water

- Air space

□ *After listing all of these factors, ask which of them* will not *affect a soil-applied herbicide. (Nearly all could influence herbicide performance.)*

### *Soil processes that determine herbicide availability*

- *Adsorption on soil colloids*: adsorption is the chemical and/or physical attraction of a substance to a surface. When a herbicide is applied to soil, a considerable percentage of its molecules can be attached to the soil colloids so tightly that they are unavailable for uptake by plants.

– only herbicide molecules in the soil solution are available

– an equilibrium reaction occurs under most conditions

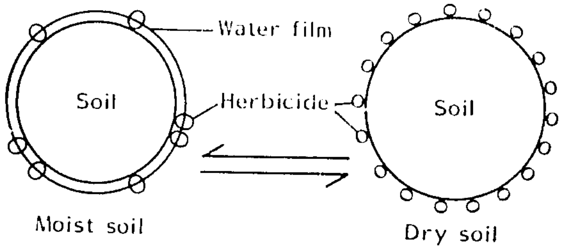
There are four primary soil factors that affect the extent of adsorption:

– *texture* — affects the available surface area. Clay is composed of small particles, so the surface area is greater; sand consists of large particles so the surface area is smaller.

– *type of clay* — montmorillonite clays have a much greater capacity to adsorb than illite or kaolinitic clays

– *organic matter content* — perhaps the most important soil factor affecting adsorption

– *soil moisture* — water can compete with herbicides for adsorptive sites on soil colloids. For soil-applied volatile herbicides, surface loss is usually much greater from moist soil than from dry soil. Some herbicides tend to be too adsorbed by dry soils to produce optimum activity. In this case, better results occur from application to moist soil so that fewer molecules are adsorbed.




- *Photodecomposition*

– light energy breaks chemical bonds in the molecule and destroys herbicides

– most herbicides are not highly susceptible to photodecomposition, but some — such as trifluralin — are broken down fast enough to cause a serious reduction in activity

– prompt mechanical incorporation into the soil is the usual solution

– in some cases, herbicide movement into the soil with rainfall or irrigation prevents serious photodecomposition

- *Chemical decomposition*

– several chemical reactions can occur in the soil to break down herbicides: oxidation, reduction, hydrolysis and hydration

– reactions occur most readily in warm, moist soil

– enzymes are frequently involved

- *Leaching*: downward movement of a substance, in solution, through the soil. (Some authors call the movement of water in the soil horizontal leaching.)

– the amount of herbicide leaching through the soil depends on its solubility, the volume of water passing through the soil, the distribution of the water, soil texture and the adsorptive relationships between herbicide and soil

☐ *Ask participants if leaching is good or bad.*

– in general, some movement of the herbicide is needed to move it into the soil for adsorption by weed roots

– undesirable for herbicide to move too deep and be ineffective on weeds or injurious to deep-rooted crops

- *Microbial break down*

– microbes can use certain herbicides for food

– can also break down herbicides rather incidentally, while working on another food source

– the breakdown of herbicides in soils by microbes is an important phenomenon

– without microbes, most herbicides would remain in the soil much longer than needed

– some herbicides are decomposed rapidly, i.e. within three to four weeks

– others resist microbial breakdown and can persist more than one year

– in general, conditions favourable to the growth of microbes will hasten herbicide decomposition

### *Herbicide response in the soil*

- Extent of herbicide adsorption depends greatly on herbicide's nature; some are quickly and tightly adsorbed (paraquat); others are much less adsorbed

- Solubility: within a given herbicide family, there is an inverse relationship between solubility and adsorption. A slight change in the herbicide molecule can greatly alter solubility

- Volatility — some herbicides can evaporate into gas or vapour and be lost

  – such materials usually need mechanical incorporation into the soil

  – volatility is affected by temperature, relative humidity, wind and soil moisture

### *Interactions*

The soil is a complex medium. Many factors can interact; any one factor can be important enough to cause herbicide success or failure. Of all environmental facters, soil moisture is likely to be the key factor in the success of soil-applied herbicides:

- Poor moisture conditions probably cause more failures with soil-applied herbicides than any other single reason

- A herbicide lying on the soil surface cannot satisfactorily control germinating weeds

- Even if a herbicide has been mechanically incorporated in the soil, sufficient moisture is needed to make a herbicide available for uptake. Weed seedlings emerging from deeper moist soil can emerge through the dry soil layer unharmed.

- The proper location of a herbicide in the soil and adequate moisture are critical factors

## Factors affecting foliage-applied herbicides

Foliage-applied herbicides are also known as "post-emergence" herbicides as they are applied after the weeds (and crop) have enough foliage to intercept adequate amounts of herbicidal spray.

☐ *Initiate this topic by asking participants to contrast the reasons for applying a herbicide to the foliage vs. the soil. For example:*

- Soil-applied herbicides are used to control weeds early in the life of the crop as well as later on

- Applications to the soil are easier; for example, worries about contact with the plant are eliminated

- Applications of soil-applied herbicides are made without certainty of the extent of the weed problem

- Foliar applications can be carried out or postponed as weed presence warrants

- Foliar control can be used for special weed problems that appear after the crop is growing

- For a foliage-applied herbicide to be effective it must:

  - reach weed plant
  - be retained on the plant's leaves
  - penetrate the leaves
  - move to the site of action
  - remain in toxic form for sufficient time to exert its effect

***Barriers to the herbicide reaching the plant***

☐ *Ask participants what these barriers could be.*

- Spray drift: the movement of spray particles outside the target area

  - particles can be phytotoxic to susceptible species
  - small droplets are more subject to drift. The smaller the nozzle orifice, the smaller the droplet; the higher the pressure, the smaller the droplet. The maximum recommended operating pressure is 1.4-2.8 kg/cm$^2$.
  - wind velocity will cause drift
  - the height of the nozzle above the target surface is a determining factor

- Volatilization

  - the change of a herbicide from a solid or a liquid to a gas is influenced by the nature of the herbicide molecule, temperature, relative humidity and the wind

– loss of a herbicide through volatility can cause a significant decrease in herbicidal activity

– some herbicide vapours are phytotoxic to susceptible plants

- Canopy effect

  – taller plants frequently protect shorter, underlying plants from herbicide applications

  – this is a particularly serious problem when contact herbicides are applied in dense weed growth

☐ *Ask what might be done to improve the coverage of shorter weeds when applying a contact herbicide in a field with weeds of widely varying heights.*

– *Answer*: Increase carrier volume and adjust the pressure to the upper limit (2.8 kg/cm$^2$), which means that the sprayer must be recalibrated.

***Factors affecting herbicide retention on the leaf***

- Plant morphology

  – narrow upright leaves (as the leaves of onions)

  – broad, flat leaves (bean plant leaves)

- Nature of leaf surface

  – waxy

  – pubescent

  – corrugated

- Nature of the spray solution

- polar

- non-polar

- May be modified by using adjuvants such as spreaders, stickers, wetting agents and oils

- Wash-off

  - rainfall, dew, irrigation

  - excessive volume of carrier and/or adjuvants

- The volatility of the herbicide

  - climatic conditions - temperature, relative humidity and the wind — affect herbicide volatility as well as the evaporation speed of the water in the spray droplet

Once retained on the leaf surface, the herbicide has four possible fates:

- It remains on the leaf surface as a crystal, which happens when the water carrier evaporates too quickly

- It enters the cuticle and remains dissolved in the non-polar portion; this happens with various weed oils

- It enters and moves in the aqueous phase along cell walls to the vascular system; examples are dalapon and amitrole

- It enters and moves directly into living cells and through them to the vascular system; an example is 2,4-D

***Herbicide absorption in the foliage***

- Entrance routes into the leaf

  - upper or lower surface, the latter being more permeable

– stomate

– cuticle (generally more important than stomatal uptake)

• Leaf cuticle: a complex layer covering the leaf, serving as a barrier to water loss in dry weather and as an entrance for external substances. Typical cutical constituents include:

– *cutin: waxes* which may be non-polar, lipophilic or short-chain esters and alcohols lacking reactive end groups

– *cutin* which is a mixture of polymerized acids and alcohols of high molecular weight containing end groups and is partly lipophilic and partly hydrophilic

– *pectins* which are amorphous and highly hydrophilic and are made up of polyuronides (sugar-like materials)

– *cellulose* which is hydrophilic, fibrillar in nature and permeable to water and polar compounds

Cutin waxes are lipophilic and thus difficult for polar, water-soluble herbicides to penetrate. Polar herbicides depend on physical openings in the cuticle to enter the leaf, finally moving along pectins and celluloses (the aqueous route). Non-polar or lipophilic compounds penetrate the lipophilic phase of the leaf structure. If too lipophilic in nature, a herbicide may have trouble penetrating hydrophilic pectin and cellulose.

Environmental conditions affect the foliar absorption of herbicides, especially water-soluble compounds. High relative humidity means that the spray droplet evaporates more slowly, more time is needed to penetrate the cuticle and that the hydrophilic portion of the leaf swells, forcing wax platelets farther apart and providing easier access for water-soluble herbicides.

• Adjuvants: increase absorption, particularly of polar materials. The exact mechanism of adjuvants is not clear, although it may have in part a solubilizing effect on the cuticle.

### *Translocation*

Many herbicides move from the point of application to other parts of the plant. Movement occurs in symplast and apoplast. Symplast refers to an interconnected, living system of plant cells functioning as a unit, including phloem and other living cells. Apoplast is an interconnected network of non-living tissue, including xylem and secondary cell walls.

Herbicides can move short distances by simple diffusion, but for true systemic action, they must move either in the xylem or phloem. Some herbicides move only in one system while others move in both. Several foliage-applied compounds move from the leaves in the symplast along with the sugars produced in photosynthesis. Examples include 2,4-D dalapon, amitrole, dicamba, picloram and glyphosate. These will frequently bypass leaves that are producing and exporting sugars.

The "source-to-sink" concept is important here. Sink refers to a site within the plant where sugars are being used to form storage materials, or where they are being actively metabolized. Sugars tend to move from leaf areas where they are manufactured (source), toward sinks. In the process, they carry along 2,4-D — which cannot move by itself along these pathways — and other herbicides.

In annual weeds, the movement of herbicides over long distances is generally not of major importance for herbicide effectiveness in comparison to other factors. In biennials, treatment at the seedling stage or the rosette stage, but before the plant sends up a flower stalk, is critical in many species. In perennials, the source-to-sink concept can be of great importance in timing a spray application.

In a plant newly emerged from vegetative parts, most of the sugar produced in photosynthesis is used to form vegetative growth. Movement is mostly upwards. When the plant reaches the bud or early-bloom stage, vegetative growth slows or ceases and most sugar produced in leaves begins to move to underground storage tissue. It is here that the herbicide can be carried along. Herbicide application at this point is usually most effective for long-term control.

Since most herbicide translocation from leaves occurs in the phloem, rapid burning or desiccation of the leaves by the herbicide is detrimental to effective translocation. Often, therefore, the fastest acting formulation of a herbicide is not used for perennial weed control. Excess herbicide rates should be avoided for the same reasons.

## Herbicide families

Each group, or family, of herbicides has distinct characteristics. Their use — including mixing and application — and the target weeds vary, thus the information presented here is divided according to specific families.

□ *Question*: Ask participants to list groups or families of herbicides. How would they do this?

### *Hormonal herbicides*

Hormones are the substances found in plants that control and regulate plant functions such as cell differentiation, root initiation, tropism, stem longitude and diameter, leaf abscission, flower initiation, apical dominance, callus formation and ovary development. At low concentrations, certain herbicides affect certain plants in a manner similar to auxin hormones. However, plants lack an intrinsic control of artificial hormones and, at higher concentrations, uncontrolled growth or a disruption of normal processes results.

*General characteristics of hormonal herbicides*

- More phytotoxic to dicotyledons than to monocotyledons with the exception of chloramben and fenac

- Generally foliage-applied

- Relatively short residual life in the soil

- Breakdown in the soil by micro-organisms, persistence is influenced by climatic and soil conditions

- Moderate to low mammalian toxicity

- Used selectively in small grain crops, pastures and non-crop areas

*Chemical groups*

- Phenoxy: 2,4-D; 2,4-DB; 2,4-DP (dichlorprop); 2,4,5-T; 2,4,5-TP (silvex); MCPA; MCPB; MCPP (mecoprop)

- Benzoic acid: dicamba; chloramben; 2,3,6-TBA

- Picolinic acid: picloram

*Specific chemical groups*

- Phenoxy

  – basic molecule includes aromatic (benzene) ring with an oxygen atom bonded directly to the ring and a carboxyl group (acid) separated from the oxygen atom on the ring by an aliphatic chain of one or more carbon atoms

  – substitutions are possible on the ring and carboxyl group

  – short-chain ester substitutions on the carboxyl group result in a volatile, non-polar, lipophilic compound

  – with long-chain esters, volatility is low

  – most often applied as amine, sodium or ammonium salts

  – moves from leaves with photosynthates — thus it is important to apply herbicides when perennial plants are accumulating food reserves

– 2,4,5-T and 2,4,5-TP are especially effective in the control of woody perennials

– 2,4-DP (dichlorprop) and 2,4,5-T and 2,4,5-TP have a longer soil life than other herbicides of this family

– highly toxic by-product, dioxin, can form during manufacturing process of 2,4,5-T, but careful temperature control has reduced this problem to insignificant levels in recent decade

- Benzoic acids

  – chloramben is effective only when applied pre-emergence; also effective in controlling annual grass weeds

  – dicamba and 2,3,6-TBA are translocated in the plant in both photosynthate and transpiration streams; can also be excreted or leaked from plant roots, to be reabsorbed by the roots of adjacent plants

  – salt forms are readily leached in the soil

  – dicamba and 2,3,6-TBA used for the control of annual and perennial broad-leaved weeds; especially effective for deep-rooted species such as *Convolvulus arvensis*

  – 2,3,6-TBA may persist in soils for two to three years at rates of 10-20 kg/ha

  – dicamba is often used to complement phenoxy compounds to control certain species such as *Polygonum* spp., *Rumex* spp., *Stellaria media* and *Lamium* spp.

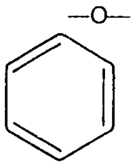
- Picolinic acid

  – absorbed by foliage and roots; highly effective in control of certain trees and shrubs when soil applied

  – long residual life in the soil; may persist two to three years in dry climates

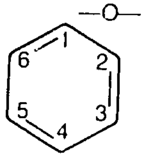
—

## Phenoxy chemistry

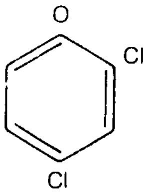
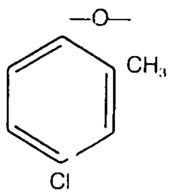
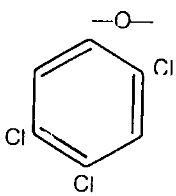
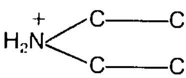



phlenyl ring
plus O – phenoxy

Basic phenoxy group




Numbering system

| *Phenoxy groups* | *Acid groups* | *Derivatives* | |
|---|---|---|---|
|  2,4-dichlorophenoxy (2,4-D) | $—CH_2—C(=O)—O—$ acetic | $H^+$ | acid |
| | | $Na^+$ | sodium salt |
| | | $K^+$ | potassium salt |
| | | $NH_4^+$ | ammonium salt |
| | | $H_2\overset{+}{N}R$ | amine salt [water soluble if Rs (carbon chains) are short] |
|  2-methyl-4-chlorophenoxy (MCP—) | $—CH(CH_3)—O(=O)—O—$ propionic | –R | ester: for example, butyl ester $—CH_2—CH_2—CH_2—CH_3$ —chain is less than 5C, highly volatile —chain 5C or more or with oxygen in the chain resulting in low-volatile ester |
|  2,4,5-trichlorophenoxy (2,4,5–T–) | $–CH_2–CH_2–CH_2–C(=O)–O–$ butyric |  | oil-soluble amine (carbon chains are 10-14 Cs long) |

– high mobility in soil water

– up to 100 times more biological activity than 2,4-D

– long residual life, high mobility in soil water and its potency necessitates the careful use of picloram to avoid the contamination of non-target areas

– rather weak on *Cruciferae* species

***Triazines, ureas and uracils***

- All soil-applied, but some also have foliar activity

- All are taken up by the roots and moved in xylem, but the more soluble also have contact activity when used with certain adjuvants

- All are effective against germinating broad-leaved and grass weeds

- All are low in solubility from a formulation standpoint and are formulated as wettable powders, flowables or granules; solubility ranges from 5 to 3 000 pp in $H_2O$

- Most have to be "activated" by rainfall or sprinkler irrigation to move them into the soil

- Most are selective primarily according to the difference in rooting depth

  – herbicides stay in top layer of soil

  – weeds germinating in this layer are killed

  – crops with roots below this layer are tolerant

- Degree of downward movement depends on:

– solubility of herbicides within family

– adsorptive qualities of herbicide

– type and quantity of clay in soil

– organic matter content of soil

– moisture content of soil at the time of application and on how soon rainfall or irrigation follows

- All are known to inhibit Hill reaction in the photosynthetic process

- Volatility and photodecomposition are low, so herbicides can stay on the soil surface for some time

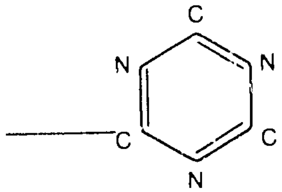
- All are soil sterilants at high rates; more persistent herbicides of these groups can present management problems

- All have low mammalian toxicity

- Slow to act on susceptible weeds

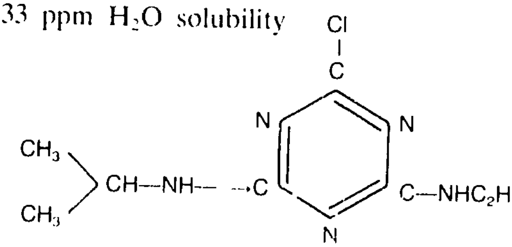
*Triazines*

- Basic triazine structure:



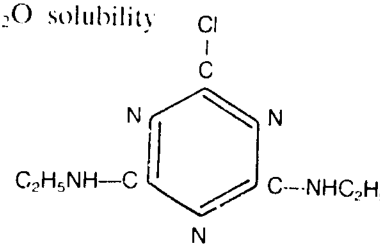
- Examples:

  – *atrazine*: 33 ppm $H_2O$ solubility




  uses: maize, sorghum, sugar cane, pineapple, conifer reforestation and others

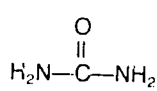
  – *simazine*: 5 ppm $H_2O$ solubility




  uses: maize, citrus, fruit and nut trees, pineapple, ornamentals, sugar cane and others

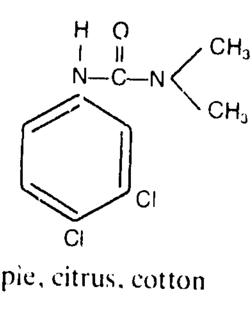
*Substituted ureas*

- Basic urea structure:



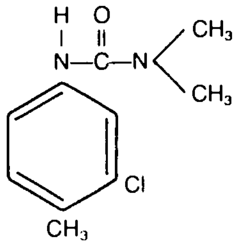

- Examples:

  – *diuron*: 42 ppm $H_2O$ solubility




  uses: wheat, barley, sugar cane, pineapple, citrus, cotton

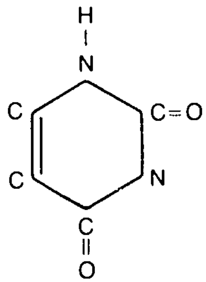
– *chlortoluron*: 70 ppm $H_2O$ solubility



uses: control of weeds in cereal grains

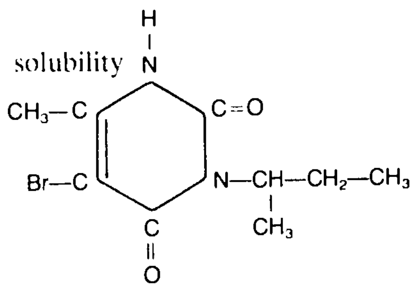
*Uracils*

- Basic uracil structure:



- Example:

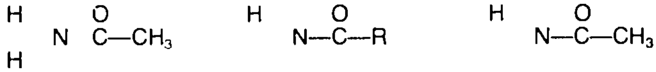
  – *bromacil*: 815 ppm $H_2O$ solubility



uses: citrus, pineapple, non-cropland

***Acid amides***

- Basic derivatives:



Acetamide | Anilide or phenylamide | Acetanilide

- Most effective against seedling grass weeds, but also control some annual broad-leaved weeds

- Generally low mammalian toxicity

- Generally soil-applied pre-emergence. Incorporation of 2-4 cm by rainfall, sprinkler irrigation or mechanically, improves performance. Propanil is an exception — strictly foliage-applied.

- Soil-applied, inhibit germination and cell elongation of emerging roots and shoots. Foliage-applied, affect photosynthesis and display contact action.

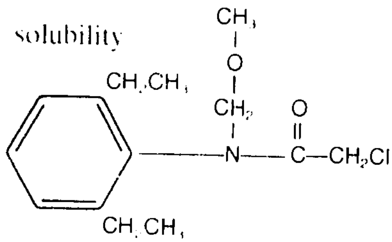
- Primarily absorbed by roots and shoots, depending on particular herbicide and weed

- Selectivity primarily biochemical

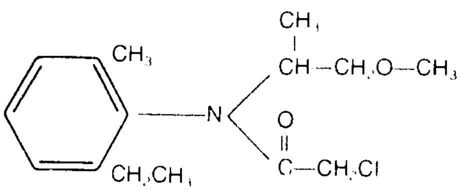
- Generally, relatively short persistence in soil; considerable microbial degradation

- Examples:

  – *alachlor*: 242 ppm $H_2O$ solubility

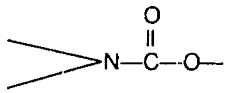



  – *metolachlor*: 530 ppm $H_2$ solubility




uses: weed control in maize, soybeans, potatoes, cotton and many others; used with several broad-leaved killers

### *Carbamates*

- Basic carbamate structure: 

- Fairly volatile

- Microbial degradation is fast under warm, moist conditions

- Need rainfall, overhead irrigation or mechanical incorporation

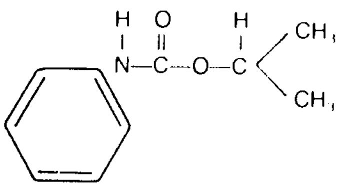
- Control many germinating and seedling grasses and some broad-leaved weeds

- Absorbed through the coleoptiles of emerging grass seedlings and to a lesser degree through roots

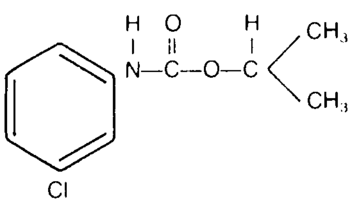
- Act on plants by inhibiting cell division

- Examples:

  – *propham*: 250 ppm $H_2O$ solubility

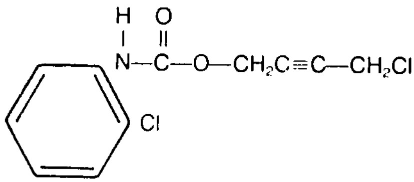


  – *chlorpropham*: 88 ppm $H_2O$ solubility



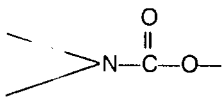
uses: weed control in seedling legumes, perennial grass crops, ornamentals and dodder (*Cuscuta* spp.) control in legumes

– *barban*: 0 ppm $H_2O$ solubility



uses: primarily an early post-emergence wild oat killer in wheat, barley, peas and sugar beets

### *Thiocarbamates*

- Basic thioocarbamates structure: 

- Require mechanical incorporation in the soil because of their extreme volatility

- Most effective against annual grasses, but also control some perennial grasses and some broad-leaved weeds

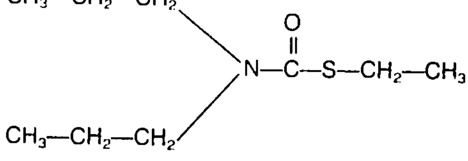
- Absorbed by the plant, mostly through the shoot

- Inhibit cell division

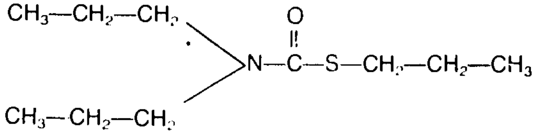
- Biologically active in the soil only for a few weeks

- Examples:

  – *EPTC*: 370 ppm $H_2O$ solubility

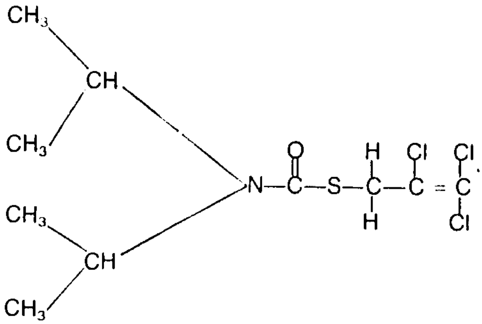


– *vernolate*: 90 ppm $H_2O$ solubility



uses: weed control in maize, soybeans, groundnuts, potatoes and many other crops

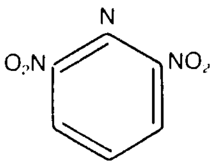
– *triallate*: 4 ppm $H_2O$ solubility



uses: wild oat control in wheat, barley, lentils and peas

### *Dinitroanilines*

- Basic dinitroaniline structure:



- Most members of this family require mechanical incorporation for one or more of the following reasons:

  – low solubility in water

  – photodecomposed

  – somewhat volatile

- Most effective against seedling grass weeds, but also control some annual broad-leaved weeds

  - absorbed by roots and shoots, but translocation is very limited

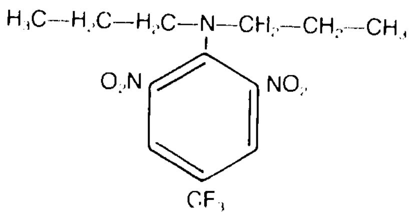
  - inhibit celle division in the root and shoot of germinating seedlings

  - selectivity is often due to herbicide placement in the soil

  - herbicide residues in soil may be active long enough to cause problems in rotation crops

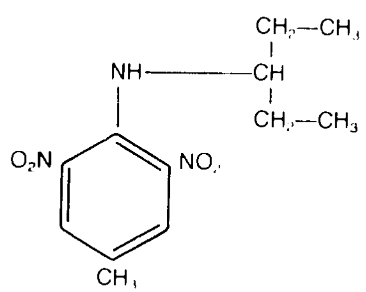
- Examples:

  - *trifluralin*: 0.3 ppm $H_2O$ solubility




uses: cotton, soybeans, groundnuts, beans, potatoes and many more crops

  - *pendimethalin*: 0.5 ppm $H_2O$ solubility




uses: maize, soybeans, cotton, groundnuts, rice, sunflowers, potatoes and many others

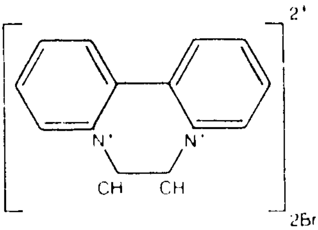
### *Bipyridyliums*

- Foliage-applied
- Seldom move in the plant
- Highly soluble in water
- No soil activity
- Symptoms may be seen within a few hours
- Works much faster in bright sunlight
- Non-selective

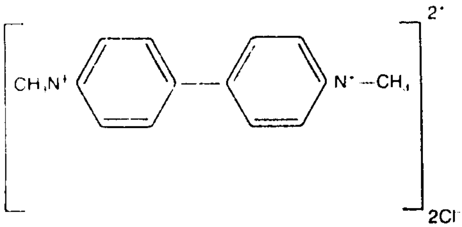
  uses: stale seed-bed, directed sprays in ornamentals, orchards or between rows of many crops

- Examples:

*diquat*




*paraquat*




### *Substituted glycine*

- Foliage-applied
- Moves throughout the plant via the symplast
- Almost no soil activity
- Negligible volatility

- Slower action than paraquat

- Non-selective, general weed killer, controls most annual and perennial grasses and broad-leaved weeds

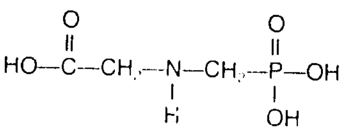
  – used in both cropland and non-cropland situations

  – selectivity is achieved by differential time of application or placement

  – pre-plant treatment for many crops

- Example:

  – *glyphosate*: high $H_2O$ solubility; sold as isopropylamine salt



***Double-ring grass-killers***

- A relatively new group of herbicides gaining rapid worldwide acceptance

- Unique herbicides because they are effective against most grasses yet have no effect on most broad-leaved species

- All are foliage-applied and have little or only a few weeks of soil activity

- All are inactive against fine fescues and give poor control of *Poa annua*

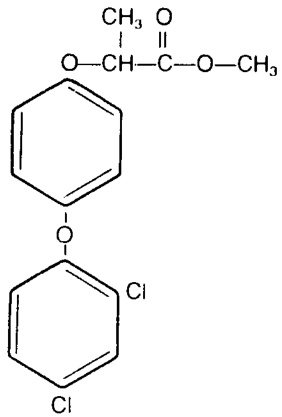
- Most are slow to act

- All are very active against maize and sorghum

- Treated weeds' growth slows or stops soon after treatment, followed by a general chlorosis; sometimes reddening develops, followed by necrosis

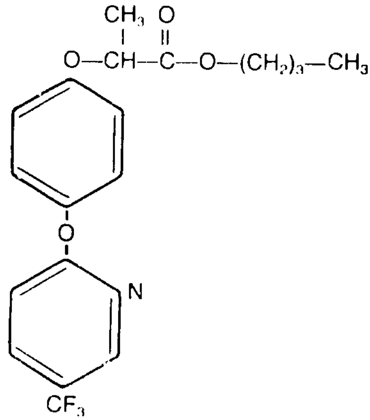
- Examples:

  – *diclofop-methyl*




uses: selective in wheat and barley: most of the others are not

  – *fluazifop-butyl*




uses: crops tested include cotton, soybeans, alfalfa, groundnuts and many vegetable crops

# 5 Conservation farming

By the mid-twentieth century, the concept of soil tillage as a necessary and integral part of modern agricultural production had become widely accepted. Farm machinery travelled over fields up to eight to ten times in one production season. Agricultural development schemes promoted by industrialized countries in developing nations often equated mechanization with modernization or with agricultural production development. However, serious ecological problems dramatized by extreme wind and water erosion in the mid-western United States in the 1930s caused many scientists to question indiscriminate tillage and caused others to reconsider plant-soil relationships, giving rise to research in alternative practices.

Conservation farming refers either to production systems aimed at reducing soil erosion and water run-off, or to systems that attempt to maintain or improve the fertility and physical properties of the soil through crop rotation, cover crops, mulches and reduced or zero tillage techniques. Although not a mandate, conservation farming may or may not demand more intensive management and the integration of crop protection practices.

## The development of tillage

History does not give us a clear record of when humans first began practising plant husbandry. Very early writings depict man struggling against weeds and tilling the soil to produce crops. Whether these early tillage practices were to provide improved conditions for seed germination and plant development or were meant to eliminate weeds is not known. In 1731, Jethro Tull stated in *Horse-hoeing husbandry* that small particles of soil (pabalum) were the food of plants and that tillage would solve the problem of plant nutrition. Although his reason for tillage is questionable, he is the one who initiated the development of modern tillage implements and their use.

The industrial revolution in England and the United States was accompanied by an exodus of many citizens from rural areas to the cities. The adoption of horse-drawn — and later, tractor-drawn — implements allowed greater output for individuals. The plow became recognized as a tool, not only for primary tillage, but also as a means to manage weeds over extensive areas. The use of horse- and tractor-drawn implements led to planting crops in rows. An ever-decreasing farm population led to larger production units per person, which encouraged manufacturers to develop even larger, more efficient machinery.

## The tillage crisis

As tillage practices spread to larger areas, problems of soil erosion caused by wind and water action reached alarming proportions. Soil compaction and the destruction of soil structure was also attributed to excessive tillage or to excessive traffic by increasingly heavy machines. In the late 1960s, the increased cost of petroleum fuel was a factor in reducing the number of passes farmers made across their fields.

Reduced tillage became more prevalent. Concurrently, from the 1940s to the present, the use of agricultural chemicals increased rapidly. Pollution from agrochemicals as a result of soil erosion and in water run-off increased. Serious erosion and soil depletion continue under traditional manual and draft animal systems of land preparation in many developing countries. Alternative practices are needed.

## The evolution of conservation tillage

Early efforts at conservation tillage concentrated on the development of machinery that would permit farmers to till fields without burying all plant residues. As the reduced-tillage concept broadened, specialized planting machinery was developed.

However, uncontrolled weed growth repeatedly appeared as a major obstacle. The development of selective herbicides enabled farmers to overcome many of the weed problems experienced with initial conservation farming systems. Herbicide use became more effective. Areas producing maize, soybeans, wheat and other crops with minimum and zero tillage techniques increased.

At present, there is a renewed interest in management practices that will reduce farmer dependence on herbicides and fertilizers. Cover crops, living mulches and the more careful timing of management practices are the most promising activities.

In many tropical areas, food is produced under traditional practices of shifting cultivation. As population pressures lengthen the cultivation period or shorten the fallow period, yields decrease and weed problems become less manageable by traditional methods.

Research indicates that production levels can be maintained by using cover crops or live mulch systems. As conservation farming systems evolve, researchers from various disciplines have slowly been drawn in collaborative efforts, developing integrated crop protection schemes.

## Research

Future research priorities in conservation farming include:

- Improved weed control through refined cultural practices and herbicide programme development for specific weed problems

- The development of living mulch systems

- Weed control during mulch establishment, especially in minimum and zero tillage systems

- Cultural and chemical control practices

- Herbicides as key to suppressing living mulch to allow crop establishment
- Improved herbicide application
- Herbicide use for special problems: parasitic and perennial weeds

# 6 Research strategies

Modern weed management is diverse and complex. While weed control research can be equally complex, it need not be. If it is planned and done in feasible segments, research can be productive and satisfying. In spite of the inherent problems of research, the important message to course participants should be to *do something*. The suggested sequence of events for research is as follows:

- Survey weed problems by region, crop, farms (with specific characteristics), by making counts in fields, asking farmers, interviewing other researchers

- Set research priorities

  – remember that the most common weed may not present the most serious problem

  – consider the chances of success

  – consider the resources needed

  – keep in mind that the individual researcher may not have a choice of projects

- Do a literature search

  – check whether research pertaining to your problem has already been done and reported

  – check available research, write letters, ask colleagues

- Study the biology and ecology of important weeds: reproduction, seed dormancy, life cycles, the depth from which a seedling can emerge, dissemination, correct identification

- Study weed response to changes in the environment: flooding, drying, shading, fertilizer applications, soil pH

- Consider the cropping system and whether the crop culture will allow certain practices:

  - delayed tillage
  - inter-row cultivation
  - mulching
  - closer planting in rows
  - reduced row width
  - crop rotation
  - zero tillage

- Conduct a herdicide screening trial based on the literature and other information and determine the following:

  - best rates
  - time of application
  - method of application
  - volume of water
  - combinations
  - formulations
  - effects of additives

- Search for the best combination of weed control methods

  - herbicides, cultivation, hand weeding

- mulching, directed herbicides
- delayed tillage, hand weeding

- Plan ahead
- Form good research habits
- Keep complete records
- Stress uniformity
- Never adjust data to obtain better results

□ □ Remind participants that good data should be accurate but will not necessarily be positive.

□ *Write and distribute reports.*

## Field research procedures

This is an ideal topic to encourage comments from participants. The notes given here are a summarized version of information presented in *Field manual for weed control research*, a publication in English and Spanish available from the International Plant Protection Center.

□ *This is an appropriate time to emphasize the importance of uniformity in research.*

### *Site selection*

□ *Draw a field on the blackboard with trees on one side, an irrigation ditch on the other side, a road on one end, the farmer's house at the other end. Ask participants to suggest where the experiment should be located.*

The following should be considered when selecting an experimental site in a field:

- Shade, water and the nutrient competition from trees
- Road dust
- Corners or row ends
- Distance to carry water
- Distance to carry sprayer or other equipment
- Irrigation
- Animals around the farmer's house
- Weed distribution
- Low spots
- Cropping history and fertilizer history
- Access by the public

### *Agreement with the landowner*

It is important that the farmer understand what is expected of him and that research has special requirements.

- How much land will be used
- What cultural practices will be used by the farmer
- Whether weedy check plots will be required
- That reduced yields may result
- What the disposition of the harvested crop will be

### *Technology level*

☐ *Question:* In the interest of research uniformity, are non-treatment production practices — which differ from those used by the farmer — appropriate? Consider irrigation, fertilizers, fine vs. rough seed-beds.

### *Plot size factors*

☐ *Ask participants to discuss plot size before you do. Guide their thinking to consider the many possible factors.*

- Research objectives
- Uniformity of weeds, crops and soils
- Type of weeds
- Type of crop
- Equipment to be used
- Irrigation system
- Availability of land
- Availability of manual labour for the establishment, care and harvest of plots

Plots should be as small as possible and still provide the information sought without excessive variability.

### *Plot borders*

Borders form the transition zone separating two different treatments. When working with row crops for yield purposes, at least three (and preferably four) rows should be used in each plot so that outside rows can be left unharvested. A common method establishes plot boundaries along the centre of a crop row; one row thus serves as the common border row of adjacent plots. This is often done when space is limited.

If space is available, a better system involves making boundaries between rows so that each plot has a separate border row on each side of the central rows, which will be harvested. When seeds are broadcast or rows are very close, a border area is also desirable. This is usually done by spraying the entire plot, but harvesting only the centre portion. Some researchers prefer to have an unsprayed zone between plots to facilitate a visual estimation of crop injury and weed control. An unsprayed zone may not be desirable because it requires a larger area and weeds are uncontrolled. Four types of control plots are:

- No weed control — used to measure losses due to uncontrolled weeds and to aid the evaluation process

- Weed free

- Common weed control practice for a region, compared with improved or best control, permits measurement of actual yield losses incurred

- Using of most commonly used herbicide for crop in question

Marking the experimental area: although not essential, neat, uniform, well-aligned plots with square angles give an experiment a pleasing physical appearance and can enhance precision.

☐ *Ask small groups of participants to lay out a square area using the 3 × 4 × 5 triangle method.*

## Evaluation of field research

Whenever possible, discussion of topics related to field activities should be followed by actual practice in the field. The type of data collected may be qualitative, quantitative or a combination of the two. Preliminary experiments may not warrant the extra effort required to obtain quantitative data. The advantages of qualitative data are that they can be gathered quickly as compared to quantitative data, and that non-treatment effects — such as animals, low spots and poor fertilizer distribution — may be considered.

The subjective methods used in qualitative evaluation are based on established arbitrary scales. Values ranging along a scale are assigned to each weed or crop species. Whenever possible, values should be assigned to separate weed species rather than by grouping grasses or broad-leaved weeds. Various scales and their relationships are given in the Table.

| Percent | Scales | | |
|---|---|---|---|
| | 0-10 | 0-5 | 1-5 |
| 0-10 | 0-1 | 0 | |
| 10-20 | 1-2 | | 1 |
| 20-30 | 2-3 | 1 | |
| 30-40 | 3-4 | | 2 |
| 40-50 | 4-5 | 2 | |
| 50-60 | 5-6 | | 3 |
| 60-70 | 6-7 | 3 | |
| 70-80 | 7-8 | | 4 |
| 80-90 | 8-9 | 4 | |
| 90-100 | 9-10 | 5 | 5 |

In selecting an evaluation scale or method, it is important to choose a system that will give an accurate reflection of treatment effects. It is also essential that the researcher explain the method used when writing the report of the experiment.

☐ *Ask participants to discuss several common problems faced by researchers in evaluating field plots.*

- Changes in weed density and species composition in the experimental area

- Treatment may control the dominant species sufficiently to allow another species to grow

• When a new species is not present in control plots, evaluation is difficult

***Evaluation types***

• Subjective, qualitative visual evaluation. A well-tested practical technique for making visual evaluations is as follows:

*Step 1:* Walk over test area to get an idea of general conditions and any crop growth or weed population differences

*Step 2:* Closely observe control plots

*Step 3:* Perform an evaluation without knowledge of the treatments in each plot (except the control plot) by moving from back to front so plot-markers cannot be read

*Step 4:* Compare results in each replication and check to ensure that any case of wide variation between replications is due to treatments and not other causes. Do this before leaving the field. If the results of two replications differ significantly, recheck their evaluation.

*Step 5:* Preferably two people should evaluate each trial independently so that results can be pooled, particularly regarding subjective data

• Quantitative evaluations

– the data provided are not influenced by the biases of the evaluator or by any inconsistencies. Quantitative data may also show differences that the evaluator missed. On the other hand, a quantitative evaluation may not overcome variation problems due to non-treatment factors.

– quantitative data collection is costly and time-consuming. It should be performed only with a planned objective in mind.

• Weed counts

– the actual density of weeds can be a useful piece of information when interpreting both visual evaluations and yield data

– weed counts, however, fail to reflect the practical effects of a few large weeds compared with many small weeds

– weed counts can be made by placing a quadrate at random locations in plots and counting plants within the quadrate

- Plant weight

– useful for some perennial crops

– useful for forage crops

– may reflect differences between a few large weeds and many small weeds

– often each sample's dry weight is determined to eliminate errors caused by unequal water loss between harvesting and the weighing of fresh samples

– dry weights alone do not yield definitive data because of the large water content variation of different species

- Plant height

– with many annual crops, forage crops and woody perennials, plant height provides a useful measurement of herbicide toxicity

– often collected to supplement final yield data and may or may not correspond to final yield

- Crop yield: the final and most important type of quantitative data. Most of the points made earlier on other types of quantitative evaluations apply equally to yield data.

– yield data must support recommendations for the cropland use of herbicides

– the number of treatments should be minimized to allow harvest during a reasonably short period, preferably a day

– experiments should be harvested by replication to reduce differences in results if the harvest is interrupted

– special problems arise for crops such as tomatoes and cucumbers that ripen over a period of weeks and must be harvested every few days. Such conditions present a high potential for error and therefore a period of time may be established for harvesting all treatments with no data taken thereafter.

– another problem develops when herbicide treatments — or weed competition — delay or hasten crop maturity. Whenever possible, each plot should be harvested at the proper time or corrections made, mainly for moisture content, particularly in seed yields.

– moisture adjustments should also be made to help standardize data. Proper data interpretation becomes difficult if moisture content is not given or if a wide range exists among different experiments. Adjustments in weights can be made using the following formula:

$$\text{Recorded weight} \times \frac{\text{100-M (measured moisture content)}}{\text{100-D (designated moisture content)}}$$

## Statistical analysis and research

Experience confirms that most statisticians do not present this discussion at a practical level for trainees in a weed management course. An experienced field agronomist with an understanding of basic statistical theory will be able to present this subject so that trainees may grasp it more readily.

*Usefulness of statistics*

- Statistics should be used by researchers to help analyse data so that reliable conclusions (inferences) can be drawn from research

- Statistics should serve as a tool for the researcher, rather than be a taskmaster

- Statistical data will not compensate for improperly identified problems, poorly defined research objectives, improper field procedures, a poor experimental design or inadequate knowledge of biological relationships

*Experimental design*

Frequently, researchers have become servants of statistical theory, which results in poorly conceived research. There has also been a tendency to design complicated field experiments that are physically and biologically unwieldy. The most simple experimental design possible should be used to permit the achievement of experimental objectives.

Experimental design is determined to a large degree by research objectives, available resources (human and physical) and the conditions of the experimental site. Further, it is advisable to consult with a reliable biometrician when planning field experiments.

## Greenhouse and field experiments

Frequently, important principles in weed management can be demonstrated with simple experiments in the field or laboratory, without the need for expensive or sophisticated equipment. These simple demonstrations are particularly beneficial in helping trainees understand certain herbicide, soil and plant characteristics that affect herbicide performance under field conditions.

□ *Select short experiments that have proved to be reliable.*

Nearly all the experiments listed here frequently require several days longer than anticipated to show the desired results. When conducting these experiments, keep in mind that some participants may wish to try similar demonstrations when they return to their organizations.

□ *Instructions should be brief. Herbicides that affect germination or seedling development should be used so that results can be seen in less time, especially in training courses of less than three weeks.*

### *Greenhouse experiments*

- *Herbicide leaching columns*: show the effect of soil type and rainfall on herbicide movement in the soil

- *Herbicide movement in the soil*: similar to leaching columns but simpler

- *Herbicide volatility*: demonstrates the effects of 2,4-D vapours on sensitive plants and the differences in volatility among derivatives of 2,4-D

- *Evapotranspiration from an aquatic environment with and without weeds*: demonstrates that aquatic weeds on the surface of a body of water accelerate water loss when compared to an identical body free of weeds

- *Movement of contact and systemic herbicides*: demonstrates the extent and direction of movement of selected herbicides applied to selected leaves of test plants

- *Crop injury from a 2,4-D contaminated sprayer:* demonstrates the high level of activity of a small amount of 2,4-D left in a sprayer

### *Implementation of greenhouse experiments*

Herbicide leaching study in different soil types

Soils: sandy and loamy (if soil is too sandy or a very heavy clay, results may not be satisfactory)

Herbicides: pendimethalin (Stomp)
at 3.0 kg a.i. (active ingredient)/ha
alachlor (Lasso) at 6.0 kg a.i./ha

Volume of rainfall: 2 cm/ha and 6 cm/ha

- Procedure

– prepare 10 × 30 cm PVC (polyvinyl chloride) tubes by cutting them lengthwise and rejoining them with tape (bamboo will work in place of the PVC pipe)

– one or two days early, fill the tubes with soil and wet the soil to field capacity

– apply herbicide. The area of soil surface may be calculated in the tube ($\pi \cdot r^2$) and the corresponding amount of herbicide applied with a micro-applicator. However, it is easier to calibrate if the desired rate of herbicide is applied as in a normal application, setting the soil-filled cylinders in an upright position and spraying over them in a normal manner as the "larger area" is being sprayed. Cylinder height should be considered when adjusting sprayer nozzle height.

– simulate rainfall by applying the correct amount of water (area of soil surface × cm of rainfall) using a can with holes in the bottom, or a sprayer, with the PVC cylinders standing upright (the water should be added slowly over a one- to two-hour period if possible)

– after 24 hours, lay the PVC cylinders in a horizontal position and carefully cut in half lengthwise with a knife or a metal sheet through the tape and soil from one side only in order to preserve the soil structure

– plant oat seeds in two straight lines 1 cm apart down the centre of the cylinder halves

– observe the seedling oats daily after germination and record your observations

## Herbicide movement in soil

- Procedure

– fill a 30 × 30 cm tray with soil to 5-10 mm from the top

– spread seeds of the test species (small seeded grass species are best) evenly over surface

– cover seeds with soil to the top of the tray and pack uniformly

– place across the tray two segments of string which have been soaked in a 2 percent mixture of alachlor or pendimethalin with water. This can be done with different soil types to demonstrate the effects of soil type on herbicide movement.

## Herbicide volatility study

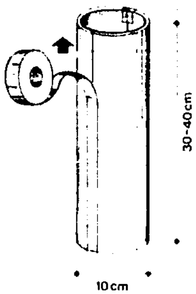
Herbicides: 2,4-D amine
2,4-D ester

Test species: tomatoes, beans or cotton

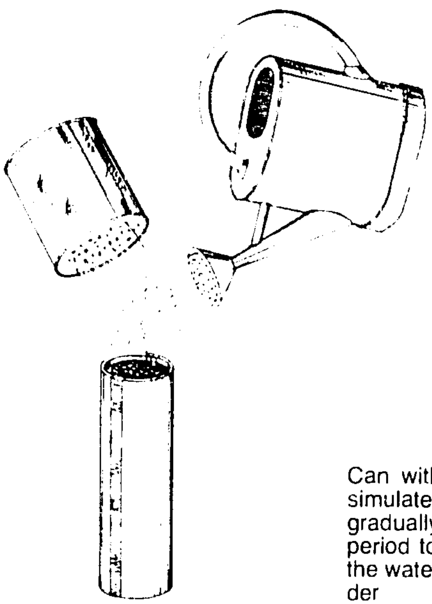
- Procedure

– test plants should be grown in pots in advance

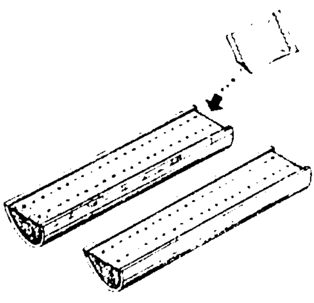
– place ten drops of the herbicide on cotton and place on jar lid (or piece of wood or stone) on the soil surface of a pot containing one or more test plants. Do not permit the herbicide to contact the plant or soil.




PVC cylinder joined with tape. To be filled with soil



Can with holes or sprayer used to simulate rainfall. This should be done gradually over a one- to two-hour period to avoid "flooding-escape" of the water down the sides of the cylinder



Cylinder split in half with test species planted in two rows in each half

– separate plants should be exposed to the amine and ester form. In some cases, both a low-volatile and a high-volatile ester will be available.

– no symptoms should appear from the amine form as it is non-volatile at normal temperatures

– cover plants and pot with a plastic bag and seal

– observe over 24 hours. If no effects are observed, keep covered for 24 hours longer.

– remove plastic bags

– continue observations. Symptoms will be slow to appear in cold conditions.

Evapotranspiration from aquatic environment with and without weeds

- Procedure

  – using any two uniform containers, fill with water to equal levels

  – place floating aquatic weeds in one, but not in the other

  – compare the water level in the two containers daily

  – record results

Movement of contact and systemic herbicides

This experiment is designed to demonstrate that certain herbicides move readily in a plant while others do not; that herbicides that move readily from treated leaves usually move with the plant sugars produced by those leaves; and that the movement of plant sugars depends upon the age of individual leaves as well as on the plant itself.

- Procedure

– use a twining broad-leaved species such as *Ipomoea* spp.

– on separate plants treat a top leaf (young), a middle leaf (medium) and a bottom leaf (old)

– dip (or paint) the selected leaf in either a 2,4-D amine 1 percent mixture in water; a glyphosate (Roundup) 1 percent mixture in water; or a paraquat (Gramoxone) 1 percent mixture in water

– be careful that herbicides do not get on untreated leaves

– observe after 24 hours and periodically for 10-12 days, recording results

Crop injury from a 2,4-D contaminated sprayer

- Objective: to demonstrate the high level of activity of even a small amount of 2,4-D residue in a sprayer

- Test species: beans, tomatoes and cotton

- Procedure

– place 1 l of a 1 percent solution of 2,4-D in a small compression or knapsack sprayer

– spray several plants of the selected species

– spray remaining liquid into a container or on a waste area

– add 1 l of water to the sprayer and spray several other plants of the test species

– repeat the preceding two steps at least twice

– observe the effects on test plants after two to four days

## *Field experiments*

- *Effect of rain on foliage-applied herbicides* (herbicide wash-off study): demonstrates the influence of the time interval between spraying and rainfall on the effectiveness of selected foliage-applied herbicides

- *Herbicide screening trial*: demonstrates differences in susceptibility of various plants to several herbicides when applied at different times and rates

- *Pre-emergence and post-emergence herbicide trials in a common crop*: demonstrates the effectiveness of several commercially recommended herbicides in a common crop when applied pre-emergence and post-emergence to the crop

## *Implementation of field experiments*

### Herbicide wash-off trial

- Objective: to demonstrate the effect of rainfall at various intervals following herbicide application

- Procedure

  – in a designated area (preferably with a uniform weed or crop population) each participant group should spray separate 1 × 5 m plots with the following herbicide treatments.

    · paraquat (Gramoxone) at 1 kg a.i./ha
    · glyphosate (Roundup) at 1 kg a.i./ha
    · 2,4-D at 0.5 kg a.i./ha
    · other post-emergence herbicides common to the area

  – immediately after spraying the herbicide, with a clean sprayer, spray 1 cm of water across 1-m sections of the plots and then at intervals of 1/2 hour, 1 hour and 2 hours until there is no wash-off

– repeat experiment, if desired, using a surfactant with the herbicides, remembering that 1 cm of rainfall = 10 l/m²

## Herbicide screening trial

- Objective: to observe the effects of different herbicides, their time of application and dosage on various plant species

- Procedure

  – plant two rows each of five to seven of the most common crops of the region, with a spacing of 50 cm between rows

  – apply herbicides in strips perpendicular to the planted rows across all crop species

  – each herbicide should be applied pre-emergence and post-emergence at two or three rates to show the effects of the time of application and herbicide dose

□□ In the case of a training course of only three to four weeks, the trial for post-emergence application should be planted sufficiently in advance so that they are well established, with three to five true leaves, when the course begins.

□□ For the pre-emergence trial, participants should mark the plots, plant and spray so that they will have the benefit of hands-on field experience.

□□ It is advisable to divide the trainees into groups of four to six. Each group may be assigned two herbicides at several rates so that each person has the experience of actually applying a treatment. Several replications of each treatment should be included.

□□ It is often helpful if the area sprayed with herbicide be 20-25 cm less than the actual plot width. This allows a "check plot" on the border of each plot so that effects may be recognized more easily.

## Pre- and post-emergence herbicide experiment

A pre-and post-emergence experiment should be established in a crop common to the region using commercially available herbicides. Trainees should be responsible for marking out and spraying the plots in the pre-emergence trial. The crop should have four to five true leaves for the post-emergence trial. Experimental plans are shown (see Tables) for a pre-emergence herbicide trial in wheat to show the type of experimental design which may be used. The same scheme may be used for the post-emergence trial.

- Sample plot plan (1 plot = 3.6 × 5.0 m²)

**Pre-emergence herbicides in wheat**

| *Chemical* | *Trade name* | *Dosage* (kg a.i./ha) | *Commercial product* (per plot) |
|---|---|---|---|
| Methabenzthiazuron | Tribunil 70% w.p.[1] | 2.0 | |
| Methabenzthiazuron | Tribunil 70% w.p. | 4.0 | |
| Chlortoluron | Dicuran 500% f.w.[2] | 1.0 | |
| Chlortoluron | Dicuran 500% f.w. | 2.0 | |
| Diclofop | Iloxan 28% e.c. | 1.0 | |
| Diclofop | Iloxan 28% e.c. | 2.0 | |
| Isoproturon | Tolkan 50% w.p. | 1.0 | |
| Isoproturon | Tolkan 50% w.p. | 2.0 | |

[1] wetting powder [2] flowable, wettable emulsifiable concentrate

| **Treatment** | **Plot plan** Replications* I | II | III | IV |
|---|---|---|---|---|
| 1 | 105 | 201 | 309 | 402 |
| 2 | 107 | 205 | 305 | 409 |
| 3 | 101 | 206 | 308 | 404 |
| 4 | 109 | 207 | 303 | 406 |
| 5 | 102 | 208 | 307 | 401 |
| 6 | 103 | 202 | 304 | 407 |
| 7 | 104 | 209 | 302 | 408 |
| 8 | 106 | 203 | 306 | 405 |
| 9 | 108 | 204 | 301 | 403 |

* Results of random number generation to determine which treatments to be used in which plots

# 7 Weed control in crops

To arrive at rational weed control recommendations, a large body of information on the biology of the crops and weeds involved is necessary. Local soil and climatic conditions, cropping patterns, rotations and cultural practices must also be known. An outline is presented in this section to guide a discussion in a logical and orderly progression so that this goal may be achieved.

If leading questions are asked, as is suggested, even those instructors unfamiliar with an area or a particular crop should be sufficiently informed to help trainees identify areas on which to focus attention in order to solve weed problems.

## Information gathering

*Ask participants to outline specific information.*

- Crop(s) and weeds
  - life cycles
  - growth habits
  - competitive ability: seedling vigour, height, density
  - adaptability: traditional or introduced variety
- Farmers' socio-economic situation
  - large vs. small
  - commercial vs. subsistence
  - resources: land, capital, access to credit, labour supply, price of labour, price of herbicides and other inputs, technical capacity of the farmer, etc.

- Physical environment
  - temperature
  - rainfall pattern
  - topography
  - soil fertility, pH
  - drainage
- Cultural practices
  - land preparation
  - planting dates
  - seed source: clean vs. contaminated, germination, etc.
  - fertilization
  - irrigation
  - tillage practices
  - use of weeds for human or animal consumption
  - are fields pastured following harvest?
  - fallow periods: are the weeds permitted to produce seeds?
- Cropping patterns
  - when is the crop planted?
  - how many cycles per year?
  - is crop rotation practised?

- crop spacing and density
- intercropping or relay cropping
- are certain weeds associated with certain crops?

- Weed control methods
  - physical: manual or mechanical?
  - chemical
  - cultural
  - biological
  - integrated
  - others

☐ *Ask participants to discuss the outlined material.*

- Do socio-economic conditions pose immediate constraints on potential weed control methods?
  - land, labour, capital
  - technical capabilities
  - others

- How might cultural methods be used to reduce the competitive ability of weeds?
  - seed-bed preparation
  - stale seed-bed method
  - pre-irrigation
  - more vigorous variety

- spacing and density of crop
- time of planting
- fertilization: when, how much, broadcast or banded?
- irrigation if needed or available
- others

- How might physical weed control methods be used?

  - manual/mechanical weeding
  - smothering with mulches: what materials are available? of living mulches, what species are available? is their life cycle compatible with the cropping pattern?
  - fire
  - flooding

- Potential for biological control

  - have biotic agents been introduced in similar areas which might serve here? (Biological control does not provide a workable control method for immediate needs if some agent has not already been introduced in the country.)

- Herbicides

  - availability of appropriate, registered herbicides
  - cost
  - residue potential for associated or rotational crops
  - availability of application equipment
  - technical capability of farmer to apply them correctly

– danger of phytotoxicity to neighbouring crops

– restrictions imposed by weather patterns

– human and environmental safety

– information available on the use of a given herbicide in the same situation in other areas of the country/world

• How can several weed control methods be integrated to improve overall control?

## Plan of action

Once the suggested information has been compiled, the group should be able to identify appropriate weed control methods to pursue or identify several alternatives which may be tested under experimental control.

# 8 Extension methods

The challenge of conveying information to farmers is worthy of a complete training course. All the methods and problems of extension cannot be covered thoroughly in a weed management course. Nevertheless, participants should be aware of the importance of the extension process.

☐ *Ask small groups of participants to prepare their thoughts on selected questions or problems for presentation to the group.*

The following topics could be assigned for advanced preparation or presented by the instructor during the discussion:

- How effective is the existing extension effort?
- What factors limit effectiveness?
- Are resources available to improve the system?
- What methods are appropriate to convey information to farmers?
  - publications
  - speeches
  - radio
  - television
  - demonstrations
  - field days
- Communication between extension and research personnel

- Research by extension personnel

- Extension by research personnel

- Differences between extension methods for large- and small-scale farmers

- The role of universities in research and extension

- The importance of cultural and social mores in extension methods

# Appendixes

## Sample schedule

The following is an actual schedule of activities for an 18-day training course:

*Day 1*

Arrival and registration of trainees at training centre and assignment of rooms

*Day 2*

| | |
|---|---|
| 09.00-10.00 | Opening ceremony and tea |
| 10.00-13.00 | Logistics, organization and introduction to course<br>• Group and individual photos<br>• Introduction of sponsoring organization<br>• Introduction of instructors<br>• Participants introduce themselves<br>• Pre-course exam |
| 14.00-15.00 | Safe use of pesticides |

*Day 3*

| | |
|---|---|
| 08.00-08.30 | Review |
| 08.30-10.00 | Field research techniques |
| 10.30-16.00 | Introduce sprayers and sprayer calibration |

*Day 4*

| | |
|---|---|
| 08.00-10.00 | Herbicide calculations |
| 10.00-16.30 | Field research, including sprayer calibration |

*Day 5*

| | |
|---|---|
| 08.00-08.30 | Review calculations and calibration<br>Introduce more field experiments |
| 08.30-13.00 | Field research |
| 14.00-14.30 | Introduce greenhouse experiments |
| 14.30-16.00 | Greenhouse experiments<br>Give homework on calculations |

*Day 6*

| | |
|---|---|
| 08.00-08.30 | Review application problems from previous day |
| 08.30-10.00 | Definitions and costs of weeds to society |
| 10.30-10.45 | Discuss homework |
| 10.45-12.30 | Weed interference |
| 12.30-13.00 | Contest: lay out square plot |

| | |
|---|---|
| 14.30-15.00 | Demonstrate gas-powered backpack sprayer and $CO_2$ research sprayer |
| 15.00-16.00 | Herbicide formulations and demonstration |
| 16.00-16.15 | Plant herbicide leaching columns |

*Day 7*

| | |
|---|---|
| 08.00-08.30 | Review weed competition and herbicide formulations |
| 08.30-10.00 | Principles of weed control and non-chemical methods |
| 10.30-12.00 | Classification of herbicides |
| 12.00-12.30 | Evaluation of pot experiments |
| 12.30-13.00 | Treat weeds with paraquat or 2.4-D on selected leaves |
| 14.00-14.30 | Discussion of pot experiments |
| 14.30-16.00 | Characteristics of herbicides affecting performance |

*Day 8*

| | |
|---|---|
| 08.00-08.30 | Review |
| 08.30-09.30 | Discuss tillage equipment |
| 09.30-12.30 | In field to discuss evaluation methods, evaluate field plots and observe tillage equipment |
| 14.00-15.00 | Review field plot evaluations and equipment |
| 15.00-16.00 | Discuss statistics for field research |

*Day 9*

| | |
|---|---|
| 08.00-08.15 | Review arrangement of replications in field |
| 08.15-09.30 | Biology of weeds |
| 09.30-10.00 | Slide set on miscellaneous application equipment |
| 10.30-11.30 | Discussion on biological control of weeds |
| 11.30-13.00 | Industry procedures for determining safety and efficacy of pesticides and fate of pesticides in the environment |
| 14.00-15.00 | Herbicide selectivity |
| 15.00-15.30 | Contest on squaring plots |
| 15.30-16.00 | Slide set on Costa Rica research with zero tillage |

*Day 10*

| | |
|---|---|
| All day | Socio-economics of weeds in cropland |

*Day 11*

| | |
|---|---|
| 08.00-09.00 | Socio-economics of weeds in cropland |
| 09.00-10.00 | Factors affecting foliage-applied herbicides |
| 10.30-11.30 | Factors affecting soil-applied herbicides |
| 11.30-12.30 | Pesticide metabolism in plants |
| 14.00-14.30 | Slide set on pesticide adjuvants |
| 14.30-15.00 | Observe weeds treated with herbicides |
| 15.00-16.00 | Review of statistics |

*Day 12*

| | |
|---|---|
| 08.00-08.30 | Review |
| 08.30-10.00 | Discuss hormonal herbicides |
| 10.30-11.00 | Demonstrate problem of sprayer contamination with 2,4-D |
| 11.00-12.00 | Discuss paraquat, ureas and triazines |
| 12.00-13.00 | Weed control in maize and sugar cane |
| 14.00-15.00 | Observe herbicide plots sprayed by participants |
| 15.00-16.00 | Weed control in vegetables |

*Day 13*

| | |
|---|---|
| 08.00-08.30 | Review |
| 08.30-10.00 | Discuss experimental design and more statistics |
| 10.30-11.00 | Discuss role of weed science societies |
| 11.00-12.45 | Weed control in wheat |
| 12.45-13.00 | Introduce sprayer calibration exercise |
| 14.00-16.00 | Sprayer calibration and calculations — field test |
| 18.00-21.00 | Dinner and presentation by a chemical company |

*Day 14*

| | |
|---|---|
| 08.00-08.30 | Review |
| 08.30-11.00 | Weeds of Pakistan |
| 11.30-13.00 | Groups work on assignments |
| 14.00-15.30 | Calibrate bicycle- and tractor-mounted sprayers |
| 15.30-16.30 | Pesticide registration in Pakistan |

*Day 15*

| | |
|---|---|
| 08.00-08.30 | Review |
| 08.30-10.00 | Weed control in rice |
| 10.30-11.00 | Weed control in cotton |
| 11.00-12.30 | Observe field experiments |
| 12.30-13.00 | Work on group assignments |
| 14.00-14.30 | Preparing research papers and using visual aids |
| 14.30-15.00 | Weed control in Pakistani forests |
| 15.00-16.00 | Work on group assignments |

*Day 16*

| | |
|---|---|
| 08.00-08.30 | Review |
| 08.30-10.30 | Participants' list of problems that interfere with their work |
| 11.00-13.00 | Group presentations of research and training plans and methods |
| 14.00-15.00 | Continue presentation of assignments of research and training plans |
| 15.00-16.00 | Review socio-economics of weed control |
| 16.00 | Discussion and presentation by a chemical company |

*Day 17*

| | |
|---|---|
| 10.00-13.00 | Final exam |

*Day 18*

| | |
|---|---|
| 08.30-09.30 | Review final exam |
| 10.00-11.00 | Presentation of certificates |

## Sample review questions

☐ *Most of the questions listed here are better used for review and to stimulate discussion. If used as exam questions, the written answers will often be too long to be read by the instructors in a reasonable time.*

- Discuss the meaning of interference and competition as they relate to crop-weed association

- Can allelopathy be used as a weed control tool?

- Discuss the statement: Weed control is part of a more general problem – vegetation management

- Explain the concept of open niches in crop production

- Under what conditions would you attempt to eradicate weeds?

- Discuss the concept of carbohydrate depletion as it relates to the control of perennial weeds

- Discuss the problem of shifting weed populations in response to control measures

- How can crop rotations influence weed problems?

- Discuss the concept of integrated weed management

- Discuss the role of the biological control of weeds on agricultural land

- Discuss hazard and toxicity in relation to the use of pesticides

- Discuss the use of $LD_{50}$ values assigned to pesticides

- List some factors influencing the hazard of a pesticide

- Discuss the on-farm disposal of unused pesticides

- Discuss the on-farm disposal of pesticide containers

- Discuss the on-farm storage of pesticides

- Give some reasons why a farmer may want to use herbicides for weed control

- Discuss the role of water in the activity of a volatile herbicide sprayed on the soil; the activity of a non-volatile herbicide sprayed on the soil; and the activity of a foliage-applied herbicide

- Discuss the factors affecting herbicide movement in a plant

- How long will a herbicide remain active in the soil?

- What is the best time to apply a translocated herbicide to a perennial weed?

- Discuss the role of soil type in herbicide activity

- Discuss herbicide leaching

- Describe how to reduce the drift of herbicide spray

- Describe how to determine the output of a sprayer in litres per hectare

- Discuss how the use of multiple cropping can reduce the impact of weeds

- Describe the different names given to herbicides

- Describe the ingredients of a herbicide formulated as a wettable powder

- Describe the ingredients of a herbicide formulated as an emulsifiable concentrate

- Discuss the importance of water or oil solubility in formulating a herbicide

- Discuss some characteristics of the groups of herbicides known as phenoxys, triazines, ureas, bipyridyliums and glycines

- Discuss the ways in which a herbicide is able to kill one group of plants without killing other plants

- Discuss the role of an emulsifying agent as used in the preparation of an emulsifiable concentrate

- Compare the management or use of two soil-applied herbicides, one with a solubility in water of 20 ppm and the other with a water solubility of 400 ppm

- Discuss several methods commonly used to classify herbicides

- Discuss the ways in which a herbicide might pose a threat to non-target plants

- Name factors affecting foliage-applied herbicide performance

- Discuss the relationship between soil type and herbicide residues

- Discuss the management of a soil-applied herbicide known to be highly volatile

- Discuss the management of a soil-applied herbicide known to be extremely low in water solubility

- Discuss the role of wetting agents in herbicide formulation and use

- Discuss how a shift to zero or minimum tillage crop production might influence the weed population on a farm

- What are some of the reasons a broadcast sprayer might leave strips of uncontrolled weeds in a treated field?

- Do you think the chemical industry is taking enough care to ensure that their chemicals are safe?

- Discuss the concept of risk-benefit

- Discuss some factors that influence the activity of a foliage-applied herbicide

- Discuss the fate of herbicides applied to the soil

- Discuss the possible reasons for using more than one herbicide on a crop

- Discuss two ways that herbicide volatility can be a problem to the user

- How can you confirm suspected herbicide residues in the soil?

- Why should surfactants not be added to all herbicides?

- Is there any value in a herbicide that controls weeds for only half of a crop cycle?

- How would you decide how much herbicide to put in a sprayer for a spot spraying of weeds?

- Give some examples of weed control practices that are directed at the crop rather than the weeds

- Why should an integrated approach to weed control be recommended to farmers?

- Explain the concept of herbicide selectivity by time

- Explain what research steps are taken to ensure that biocontrol agents will not feed on economic plants

- Discuss some precautions to be taken when using 2,4-D

- Describe how the leaching of herbicides can be good or bad

- Describe the practice of delayed tillage

- Why are herbicides formulated?

- Discuss the concept that weed control cannot increase yields but only reduce yield losses

- Two fields are side-by-side. Both have been sprayed with the same herbicide at the same rate on the same day. Control was good in one field and poor in the other. Give some possible reasons for these results.

- What is the difference between measuring weed losses in a crop with no weed control compared with losses after the farmer's normal practice

- Discuss how much water should be used as a carrier for herbicides

# Sample examination questions

A pre-course and final exam have proved useful components of a weed management training course. The pre-course exam will provide an accurate indication of participants' knowledge level and also emphasize that the instructors are serious about the course.

Most of the questions listed here are written to simplify the evaluation process and still provide an accurate measurement of the participants' knowledge of the topic.

- Give one way that tillage affects the germination of weed seeds

- Give three reasons why onions are poor competition for weeds

- What are three ways to prevent weed seed dispersal?

- Explain the "critical period" as it relates to weed-crop competition

- List five factors that may determine when the critical period of weed-crop competition occurs

- List three things you can do with a crop to make it more competitive against weeds

- Give the genus and species name of sample weeds

- Give four characteristics of annual weeds that enable them to compete with crops

- Give one method of killing perennial weeds without herbicides

- List three routes by which pesticides may enter the body

- Which type of pesticide exposure is considered to be most dangerous?

- Would you expect herbicide residues to be a greater problem in clay soils or sandy soils? Why?

- High pressure reduces droplet size, thus increasing the risk of drift. What other factor affects droplet size?

- List four things that might happen to a soil-active herbicide once it has been applied to the soil

- Which of the following is/are dinitroaniline herbicides: alachlor, atrazine, linuron, pendimethalin, trifluralin

- List two advantages and two disadvantages of doing on-farm research

- Why are trifluralin and EPTC often unacceptable for small-farm use?

- List three things that can be done to prevent the buildup of weeds that are resistant to herbicides

- What are two foliage characteristics that influence herbicide selectivity?

- How does a wetting agent affect a herbicide spray when it contacts a plant?

- A farmer has 90 ha of cotton to plant. He wants to apply 0.5 kg a.i./ha of trifluralin which is formulated as Treflan EC containing 48 percent a.i. His tractor-mounted sprayer has a 450-l tank and is set to apply 140 l/ha.

  *a*) How much Treflan does the farmer need to cover the full 90 ha?

  *b*) How much Treflan must he add to each full spray tank?

*c*) How many hectares can be treated with one full tank of mixture?

- How many mls of the commercial product Gesaprim (atrazine) are needed to spray 30 $m^2$ if the desired rate is 2.5 kg a.i./ha and Gesaprim is a 50 percent a.i. flowable formulation?

- Describe three ways in which a herbicide can kill weeds without harming associated crops

- Why are cone nozzles not supposed to be used to apply herbicides?

- Name a herbicide that is classified as: *a*) hormonal, *b*) contact, and *c*) soil active-systemic

- Name three major soil characteristics that influence herbicide activity

- Give three reasons why the biological control of weeds on cropland is not usually satisfactory even if good control is achieved

- List five things necessary for estimating how long a herbicide will remain active in the soil

- Describe the ideal soil moisture condition for a non-volatile soil-active herbicide

- Give four different kinds of check-plots that may be useful for field research on weed control

- List three factors that determine the volume of water a sprayer will discharge on a unit of land

- Define the term $LD_{50}$

- Give four factors to consider in deciding on the plot size for a field experiment

- List four ways the previous management of a field can affect the current weed population

- A sprayer is calibrated and uses 5 l of water in an area that is 20 × 10 m. Calculate the litres per hectare output.

- Herbicide A has an oral $LD_{50}$ rating of 500 mg/kg. Herbicide B has an $LD_{50}$ rating of 5 000 mg/kg. Which is the more toxic?

- Why is paraquat (Gramoxone) not used to control weeds by root uptake?

- Describe two ways in which to use a non-selective herbicide on a crop

- Name four items of protective clothing that should be worn when spraying and handling herbicides

- Explain the terms pre-emergence, post-emergence and pre-plant incorporated

IT IS HEREBY CERTIFIED THAT

..................................................................................................

HAVING SATISFACTORILY PARTICIPATED IN THE

# WEED SCIENCE RESEARCH SHORT COURSE

CONDUCTED AT NAIROBI, KENYA,

AUGUST 29 TO SEPTEMBER 10, 1983,

IS DULY AWARDED THIS

## *Certificate of Achievement*



| D. N. NGUGI, DEAN | J. K. GITAU | M. A. FARAH | B. F. MILLER |
|---|---|---|---|
| FACULTY OF AGRICULTURE, UNIVERSITY OF NAIROBI | DIRECTOR OF RESEARCH, MINISTRY OF AGRICULTURE, KENYA | REGIONAL PLANT PROTECTION OFFICER, FAO NAIROBI | DIRECTOR, INTERNATIONAL PLANT PROTECTION CENTER |

# WHERE TO PURCHASE FAO PUBLICATIONS LOCALLY

| | |
|---|---|
| **Algeria** | Société nationale d'édition et de diffusion, 92, rue Didouche Mourad, Alger |
| **Argentina** | Librería Agropecuaria S.A., Pasteur 743, 1028 Buenos Aires |
| **Australia** | Hunter Publications, 58A Gipps Street, Collingwood, Vic. 3066; Australian Government Publishing Service, Sales and Distribution Branch, Wentworth Ave, Kingston, A.C.T. 2604. Bookshops in Adelaide, Melbourne, Brisbane, Canberra, Perth, Hobart and Sydney |
| **Austria** | Gerold & Co., Graben 31, 1011 Vienna |
| **Bahrain** | United Schools International, PO Box 726, Manama |
| **Bangladesh** | Association of Development Agencies in Bangladesh, House No. 45A, Road No. 6A, Dhanmondi R/A, Dhaka |
| **Belgium** | M. J. De Lannoy, 202, avenue du Roi, 1060 Bruxelles. CCP 000-0808993-13 |
| **Bolivia** | Los Amigos del Libro, Peru 3712, Casilla 450, Cochabamba; Mercado 1315, La Paz |
| **Botswana** | Botsalo Books (Pty) Ltd, PO Box 1532, Gaborone |
| **Brazil** | Fundação Getulio Vargas, Praia de Botafogo 190, C.P. 9052, Rio de Janeiro; Livraria Canuto Ltda, Rua Consolação, 348 - 2° andar, Caixa Postal 19198, São Paulo |
| **Brunei Darussalam** | SST Trading Sdn. Bhd., Bangunan Tekno No. 385, Jln 5/59, PO Box 227, Petaling Jaya, Selangor |
| **Canada** | Renouf Publishing Company Ltd, 61 Sparks Street, PO Box 1008, Station B, Ottawa, Ont. KIP 5R1. Tel. (613) 238 8985. Toll-free calls in Canada: 1-800-267-4164. Telex 053-4936 |
| **Chile** | Librería - Oficina Regional FAO, Avda. Santa Maria 6700, Casilla 10095, Santiago. Teléfono 228-80-56 |
| **China** | China National Publications Import Corporation, PO Box 88, Beijing |
| **Congo** | Office national des librairies populaires, B.P. 577, Brazzaville |
| **Costa Rica** | Librería, Imprenta y Litografía Lehmann S.A., Apartado 10011, San José |
| **Cuba** | Ediciones Cubanas, Empresa de Comercio Exterior de Publicaciones, Obispo 461, Apartado 605, La Habana |
| **Cyprus** | MAM, PO Box 1722, Nicosia |
| **Czechoslovakia** | ARTIA, Ve Smeckach 30, PO Box 790, 111 27 Prague 1 |
| **Denmark** | Munksgaard Export and Subscription Service, 35 Nørre Søgade, DK 1370 Copenhagen K |
| **Dominican Rep.** | Fundación Dominicana de Desarrollo, Casa de las Gárgolas, Mercedes 4, Apartado 857, Zona Postal 1, Santo Domingo |
| **Ecuador** | Su Librería Cía. Ltda., García Moreno 1172 y Mejía, Apartado 2556, Quito |
| **El Salvador** | Librería Cultural Salvadoreña, S.A. de C.V., 7ª Avenida Norte 121, Apartado Postal 2296, San Salvador |
| **Finland** | Akateeminen Kirjakauppa, 1 Keskuskatu, PO Box 128, 00101 Helsinki 10 |
| **France** | Editions A. Pedone, 13, rue Soufflot, 75005 Paris |
| **Germany, F.R.** | Alexander Horn Internationale Buchhandlung, Friederichstr. 39, Postfach 3340, 6200 Wiesbaden |
| **Ghana** | Fides Enterprises, PO Box 14129, Accra; Ghana Publishing Corporation, PO Box 3632, Accra |
| **Greece** | G.C. Eleftheroudakis S.A., 4 Nikis Street, Athens (T-126); John Mihalopoulos & Son S.A., 75 Hermou Street, PO Box 73, Thessaloniki |
| **Guatemala** | Distribuciones Culturales y Técnicas «Artemis», 5ª Avenida 12-11, Zona 1, Apartado Postal 2923, Guatemala |
| **Guinea-Bissau** | Conselho Nacional da Cultura, Avenida da Unidade Africana, C.P. 294, Bissau |
| **Guyana** | Guyana National Trading Corporation Ltd, 45-47 Water Street, PO Box 308, Georgetown |
| **Haiti** | Librairie "A la Caravelle", 26, rue Bonne Foi, B.P. 111, Port-au-Prince |
| **Hong Kong** | Swindon Book Co., 13-15 Lock Road, Kowloon |
| **Hungary** | Kultura, PO Box 149, 1389 Budapest 62 |
| **Iceland** | Snaebjörn Jónsson and Co. h.f., Hafnarstraeti 9, PO Box 1131, 101 Reykjavik |
| **India** | Oxford Book and Stationery Co., Scindia House, New Delhi 100 001; 17 Park Street, Calcutta 700 016; Oxford Subscription Agency, Institute for Development Education, 1 Anasuya Ave, Kilpauk, Madras 600 010 |
| **Indonesia** | P.T. Inti Buku Agung, 13 Kwitang, Jakarta |
| **Iraq** | National House for Publishing, Distributing and Advertising, Jamhuria Street, Baghdad |
| **Ireland** | The Controller, Stationery Office, Dublin 4 |
| **Italy** | Distribution and Sales Section, FAO, Via delle Terme di Caracalla, 00100 Rome; Libreria Scientifica Dott. Lucio de Biasio "Aeiou", Via Meravigli 16, 20123 Milan; Libreria Commissionaria Sansoni S.p.A. "Licosa", Via Lamarmora 45, C.P. 552, 50121 Florence |
| **Japan** | Maruzen Company Ltd, PO Box 5050, Tokyo International 100-31 |
| **Kenya** | Text Book Centre Ltd, Kijabe Street, PO Box 47540, Nairobi |

# WHERE TO PURCHASE FAO PUBLICATIONS LOCALLY

| | |
|---|---|
| **Korea, Rep. of** | Eulyoo Publishing Co. Ltd. 46-1 Susong-Dong, Jongro-Gu, PO Box 362, Kwangwha-Mun, Seoul 110 |
| **Kuwait** | The Kuwait Bookshops Co. Ltd, PO Box 2942, Safat |
| **Luxembourg** | M. J. De Lannoy, 202, avenue du Roi, 1060 Bruxelles (Belgique) |
| **Malaysia** | SST Trading Sdn. Bhd., Bangunan Tekno No. 385, Jln 5/59, PO Box 227, Petaling Jaya, Selangor |
| **Mauritius** | Nalanda Company Limited, 30 Bourbon Street, Port-Louis |
| **Mexico** | Dilitsa S.A., Puebla 182-D, Apartado 24-448, Mexico 06700, D.F. |
| **Morocco** | Librairie "Aux Belles Images", 281, avenue Mohammed V, Rabat |
| **Netherlands** | Keesing Publishing Company B.V., Hogehilweg 13, 1101 CB Amsterdam, Post Box 1118, 1000 BC Amsterdam |
| **New Zealand** | Government Printing Office, Government Printing Office Bookshops: 25 Rutland Street; Mail orders: 85 Beach Road, Private Bag, CPO, Auckland; Ward Street, Hamilton; Mulgrave Street (Head Office), Cubacade World Trade Centre, Wellington; 159 Hereford Street, Christchurch; Princes Street, Dunedin |
| **Nicaragua** | Libreria Universitaria, Universidad Centroamericana, Apartado 69, Managua |
| **Nigeria** | University Bookshop (Nigeria) Limited, University of Ibadan, Ibadan |
| **Norway** | Johan Grundt Tanum Bokhandel, Karl Johansgate 41-43, PO Box 1177, Sentrum, Oslo 1 |
| **Pakistan** | Mirza Book Agency, 65 Shahrah-e-Quaid-e-Azam, PO Box 729, Lahore 3; Sasi Book Store, Zaibunnisa Street, Karachi |
| **Panama** | Distribuidora Lewis S.A., Edificio Dorasol, Calle 25 y Avenida Balboa, Apartado 1634, Panamá 1 |
| **Paraguay** | Agencia de Librerias Nizza S.A., Casilla 2596, Eligio Ayala 1073, Asunción |
| **Peru** | Libreria Distribuidora «Santa Rosa», Jirón Apurimac 375, Casilla 4937, Lima 1 |
| **Philippines** | The Modern Book Company Inc., PO Box 632, Manila |
| **Poland** | Ars Polona, Krakowskie Przedmiescie 7, 00-068 Warsaw |
| **Portugal** | Livraria Bertrand, S.A.R.L., Rua João de Deus, Venda Nova, Apartado 37, 2701 Amadora Codex; Livraria Portugal, Dias y Andrade Ltda., Rua do Carmo 70-74, Apartado 2681, 1117 Lisbonne Codex |
| **Romania** | Ilexim, Str. 13 Dicembrie No. 3-5, Bucharest Sector 1 |
| **Saudi Arabia** | The Modern Commercial University Bookshop, PO Box 394, Riyadh |
| **Singapore** | MPH Distributors (S) Pte. Ltd, 71/77 Stamford Road, Singapore 6; Select Books Pte. Ltd, 215 Tanglin Shopping Centre, 19 Tanglin Road, Singapore 1024; SST Trading Sdn. Bhd., Bangunan Tekno No. 335, Jln 5/59, PO Box 227, Petaling Jaya, Selangor |
| **Somalia** | "Samater's", PO Box 936, Mogadishu |
| **Spain** | Mundi-Prensa Libros S.A., Castelló 37, 28001 Madrid; Libreria Agricola, Fernando VI 2, 28004 Madrid |
| **Sri Lanka** | M.D. Gunasena & Co. Ltd, 217 Olcott Mawatha, PO Box 246, Colombo 11 |
| **Sudan** | University Bookshop, University of Khartoum, PO Box 321, Khartoum |
| **Suriname** | VACO n.v. in Suriname, Domineestraat 26, PO Box 1841, Paramaribo |
| **Sweden** | Books and documents: C.E. Fritzes Kungl. Hovbokhandel, Regeringsgatan 12, PO Box 16356, 103 27 Stockholm. Subscriptions: Vennergren-Williams AB, PO Box 30004, 104 25 Stockholm |
| **Switzerland** | Librairie Payot S.A., Lausanne and Geneva; Buchhandlung und Antiquariat Heinimann & Co., Kirchgasse 17, 8001 Zurich |
| **Tanzania** | Dar-es-Salaam Bookshop, PO Box 9030, Dar-es-Salaam; Bookshop, University of Dar-es-Salaam, PO Box 893, Morogoro |
| **Thailand** | Suksapan Panit, Mansion 9, Rajadamnern Avenue, Bangkok |
| **Togo** | Librairie du Bon Pasteur, B.P. 1164, Lomé |
| **Tunisia** | Société tunisienne de diffusion, 5, avenue de Carthage, Tunis |
| **Turkey** | Kultur Yayinlari Is-Turk Ltd Sti., Ataturk Bulvari No. 191, Kat. 21, Ankara. Bookshops in Istanbul and Izmir |
| **United Kingdom** | Her Majesty's Stationery Office, 49 High Holborn, London WC1V 6HB (callers only); HMSO Publications Centre, Agency Section, 51 Nine Elms Lane, London SW8 5DR (trade and London area mail orders); 13a Castle Street, Edinburgh EH2 3AR; 80 Chichester Street, Belfast BT1 4JY; Brazennose Street, Manchester M60 8AS; 258 Broad Street, Birmingham B1 2HE; Southey House, Wine Street, Bristol BS1 2BQ |
| **United States of America** | UNIPUB, PO Box 1222, Ann Arbor, MI 48106 |
| **Uruguay** | Libreria Agropecuaria S.R.L., Alzaibar 1328, c.c. 1755, Montevideo |
| **Yugoslavia** | Jugoslovenska Knjiga, Trg. Republike 5/8, PO Box 36, 11001 Belgrade; Cankarjeva Zalozba, PO Box 201-IV, 61001 Ljubljana |
| **Zambia** | Kingstons (Zambia) Ltd, Kingstons Building, President Avenue, PO Box 139, Ndola |
| **Other countries** | Requests from countries where sales agents have not yet been appointed may be sent to: Distribution and Sales Section, FAO, Via delle Terme di Caracalla, 00100 Rome, Italy |