AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D C 20523

BIBLIOGRAPHIC INPUT SHEET

FOR AID USE ONLY
BATCH 42

1. SUBJECT CLASSIFICATION

A. PRIMARY: Food production and nutrition — AH60-0000-0000

B. SECONDARY: Weeds

2. TITLE AND SUBTITLE

Field manual for weed control research

3. AUTHOR(S)

Burrill,L.C.; Cardenas,Juan; Locatelli,Eduardo

4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
1976	64p.	ARC

7. REFERENCE ORGANIZATION NAME AND ADDRESS

Or.State

8. SUPPLEMENTARY NOTES *(Sponsoring Organization, Publishers, Availability)*

9. ABSTRACT

A heavily illustrated manual of procedures for conducting field research on weed control methods. For many developing nations, weed-caused economic losses are assuming increased importance, particularly in relation to the introduction of new, high-yielding varieties and the "production package" approach. Merely testing chemicals for weed control effectiveness and safety to crops is no longer sufficient. Extensive data must be collected on herbicides and their residues. This manual has been prepared to encourage improved weed control research, and to provide flexible guidelines for conducting the crucial field experiments in weed control. Research workers should be aware that, though this publication concerns control through use of chemicals, weed control programs require integrated techniques. Seldom will chemical weed control alone yield maximum benefits; cultural, manual, and mechanical methods also need to be considered and tested. Sections of this manual discuss such topics as reviewing and defining the problem; types of field trials, location of trials; agreements with owners; level of production technology; research procedures, including establishing trials, site selection, block and plot arrangement, plot size and borders, control plots, herbicide rates, cultural practices, seeding weeds, marking experimental area, numbering plots, and equipment; research evaluations, including time of evaluation, qualitative methods, and quantitative evaluations; data analysis; recording and reporting results; safety in handling herbicides; and equivalents and conversion rates for the metric system and U.S. measures.

10. CONTROL NUMBER
PN-AAC-874

11. PRICE OF DOCUMENT

12. DESCRIPTORS

Data
Manuals
Methodology
Research
Weed control

13. PROJECT NUMBER

14. CONTRACT NUMBER
AID/CM/ta-73-23 Res.

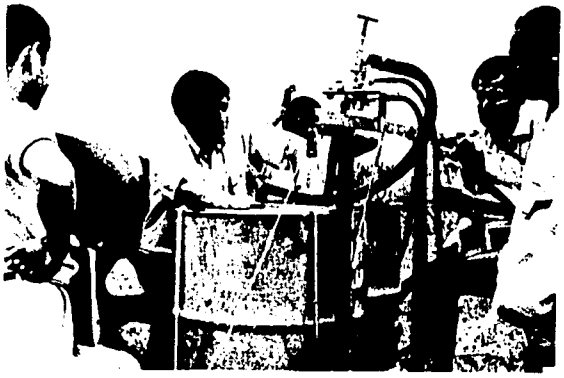
15. TYPE OF DOCUMENT

AID 590-1 (4-74)

FIELD MANUAL FOR WEED CONTROL RESEARCH

L. C. Burrill
M.S., weed science, coordinating agronomist, International Plant Protection Center

J. Cardenas
Ph.D., weed science, former staff weed research specialist, International Plant Protection Center



A. E. Deutsch
M.A., communications, leader information services section, International Plant Protection Center

E. Locatelli
Ph.D., weed science, staff weed research specialist, International Plant Protection Center

ACKNOWLEDGEMENT

Information, assistance, and support were received from a number of sources for which the authors acknowledge their deep appreciation. In particular, manuscript reviews by colleagues Dr. Jerry Doll (Centro Internacional Agricultura Tropical, Cali, Colombia), Myron Shenk and Herb Fisher (International Plant Protection Center), and Dr. Arnold P. Appleby (Department of Agronomic Crop Science, Oregon State University) were extremely helpful. Special thanks go to Douglas L. Young (Department of Agricultural and Resource Economics, Oregon State University) for drafting the chapter on statistics. The encouragement and assistance of International Plant Protection Center director Dr. Stanley F. Miller were invaluable as were the efforts of Ms. Myrna Wade who efficiently prepared numerous manuscript drafts. And finally, without the material support and interest provided by the U. S. Agency for International Development through Channing J. Fredrickson and Dr. Edward J. Rice of the Technical Assistance Bureau, the publication could not have been prepared.

FIELD MANUAL FOR WEED CONTROL RESEARCH

By/

L. C. Burrill

J. Cardenas

E. Locatelli

Edited and designed by /

A. E. Deutsch

Published by /

International Plant Protection Center

Oregon State University

Corvallis, Oregon 97331 / USA

Copyright by /

International Plant Protection Center, 1976

U. S. Library of Congress

Catalog Card No. 76-14145

Report #20-A-76 **$US 5.00**

Contents

1 INTRODUCTION

3 1 RESEARCH PLANNING
3 1.1 REVIEW AND DEFINE THE PROBLEM
4 1.2 TYPES OF FIELD TRIALS
5 1.2.1 Primary Screening Trials
5 1.2.2 Secondary Screening Trials
5 1.2.3 Yield Trials
5 1.2.4 Regional Trials
5 1.2.5 Demonstration Plots
6 1.2.6 Special Studies
A. Soil residue studies
B. Formulation studies
C. Volume of carrier studies
D. Competition studies
E. Miscellaneous studies
8 1.3 LOCATION OF TRIALS
8 1.4 AGREEMENT WITH LAND OWNER
9 1.5 LEVEL OF PRODUCTION TECHNOLOGY

11 2 RESEARCH PROCEDURE
11 2.1 ESTABLISHING TRIALS
11 2.2 SITE SELECTION
11 2.3 BLOCK AND PLOT ARRANGEMENT
13 2.4 PLOT SIZE
15 2.5 PLOT BORDERS
15 2.6 CONTROL PLOTS
15 2.7 HERBICIDE RATES
16 2.8 CULTURAL PRACTICES
16 2.9 SEEDING WEEDS
17 2.10 MARKING EXPERIMENTAL AREA
18 2.11 NUMBERING PLOTS
19 2.12 EQUIPMENT
2.12.1 Manually Pumped Sprayer
2.12.2 Compressed Air Sprayer
2.12.3 Compressed Gas Sprayer
2.12.4 Bicycle Wheel Sprayers
2.12.5 Engine Driven Tractor Mounted Sprayers

2.12.6 Logarithmic Sprayers
2.12.7 General Comments on Equipment
A. Agitation
B. Pressure gauges and pressure regulators
C. Hose and boom
D. Nozzles
E. Nozzle screens
F. Nozzle overlapping
G. Effect of pressure
H. Changing output
2.12.8 Application of Granular Herbicides
2.12.9 Calibration and Calculations
A. Area Basis
B. Volume Basis
C. Field Sprayers
27 2.13 PRECAUTIONS AND TECHNIQUES
27 2.14 SOIL PERSISTENCE TRIALS
2.14.1 Combined Trials
2.14.2 Specific Residue Trials
31 **3 RESEARCH EVALUATION**
31 3.1 TIME OF EVALUATION
32 3.2 QUALITATIVE METHODS OF EVAULATION
34 3.3 QUANTITATIVE EVALUATIONS
3.3.1 Weed Counts
3.3.2 Plant Weight
3.3.3 Plant Height
3.3.4 Sampling Area
3.3.5 Crop Yield
37 **4 DATA ANALYSIS AND STATISTICS**
37 4.1 PLANNING FOR ANALYSIS
38 4.2 STATISTICAL ANALYSIS
38 4.3 ECONOMIC ANALYSIS
39 **5 RECORDING AND REPORTING RESULTS**
39 5.1 BACKGROUND INFORMATION
40 5.2 MATERIALS AND METHODS
40 5.3 APPLICATION DATA
40 5.4 RESULTS

43 **6 SAFETY**

43 6.1 HERBICIDES AND SAFETY

45 6.2 HERBICIDE STORAGE

45 6.3 DISPOSAL

45 6.4 APPLICATION
6.4.1 WInd
6.4.2 Protective Gear

47 **7 MEASURES, EQUIVALENTS, CONVERSIONS AND RATES**

47 7.1 THE METRIC SYSTEM

48 7.2 U.S. MEASURES

49 7.3 EQUIVALENTS
7.3.1 Linear
7.3.2 Area
7.3.3 Volume
7.3.4 Liquid
7.3.5 Mass

52 7.4 CONVERSION FACTORS
7.4.1 Temperature

53 7.5 DATA TABLES
7.5.1 Rate of Travel
7.5.2 Weight-Volume Relationship
7.5.3 Spray Concentration Conversions
7.5.4 Area Equivalents
7.5.5 Equivalents for Various Concentrations
7.5.6 Equivalent Rates for Liquid Application
7.5.7 Equivalent Rates for Dry Material Application
7.5.8 Grams of Treatment Required at Various Rates for Indicated Areas

Introduction

The science of weed control has a solid basis for gaining importance worldwide. Profitable production and harvesting of quality crops depend on control of weeds, a fact recognized by agriculturally-developed nations. For many other nations just launching programs aimed at achieving agricultural self-sufficiency and escaping present economic burdens, weed-caused economic losses and production setbacks have assumed increased importance, particularly in relation to the introduction of new, high-yielding varieties and the "production package" approach.

As with any science, weed control will continue maturing only as its practitioners expand and refine their research techniques. Merely testing chemicals for weed control effectiveness and safety to crops is no longer sufficient. The safety of man and preservation of his environment must now be clearly demonstrated through collecting extensive data concerning herbicides and their residues.

The **FIELD MANUAL FOR WEED CONTROL RESEARCH** has been prepared to encourage improved weed control research. It also has a second goal: to provide flexible guidelines for successfully carrying out the crucial field segment of weed control experimentation and research.

Research workers should be aware that, although this publication primarily concerns control through use of chemicals, weed control programs require integrated

application of other technologies. Seldom will chemical weed control alone yield maximum benefits; cultural, manual, and mechanical methods also warrant consideration. Weed biology and ecology research techniques often bear similarity for herbicidal, as well as non-herbicidal, weed control. In many instances several weed control methods can be combined effectively in a single trial.

The following material makes no pretense of being all-inclusive (aerial application and aquatic weed research have been omitted). However, the authors' combined years of experience have yielded a body of information that can assist beginning researchers to establish viable weed control research programs. More experienced investigators also may find numerous useful ideas.

L. C. Burrill
J. Cardenas
E. Locatelli

Corvallis, Oregon / USA

June, 1976

1 Research Planning

- ☐ ***Survey the area***
- ☐ ***Identify problems***
- ☐ ***Review literature***
- ☐ ***Select type of trials***

1.1 REVIEW AND DEFINE THE PROBLEM

The common phases of all sound research programs are:

Planning
↓
Execution
↓
Data Collection, Evaluation, and Interpretation
↓
Reporting Results

Planning a research program first calls for a concise definition of the problem (or problems) and a clear understanding of their magnitude. In the case of weed problems, which generally associate with a geographical region and crop, the initial field survey should encompass a large enough physical area to firmly establish the overall situation. Visiting the region at different periods of the growing season to observe the problem during various stages, consulting with local farmers, meeting with commercial enterprises, and discussing the situation with area extension agents all help to gain a realistic perspective of the problem.

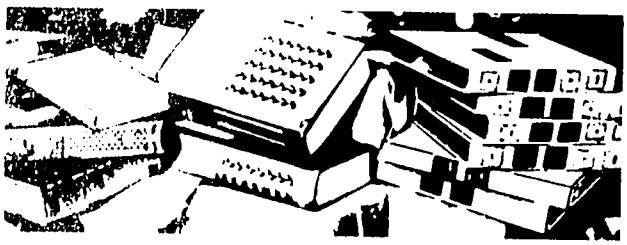
Frequently a field review will determine that the initial problem is, in reality, a complex of several problems. Each individual problem then should be ranked in importance, and also assigned a second ranking according to feasibility of being solved. It may be desirable to give highest priority to problems that can be easily solved rather than to more serious, time-consuming, and nearly unsolvable problems.

The careful researcher considers the possible consequences of concentrating on, and eliminating, a primary problem. The secondary problem, under certain conditions, may then assume greater magnitude than the original primary problem. For example, in some corn growing areas of the world a relatively innocuous weed such as *Cucumis melo*, (a wild cucumber) may be the primary weed and the underlying secondary problem may be a potentially more aggressive weed such as *Leptochloa filiformis* (sprangletop), an annual grass. Selective control of the wild cucumber may result in lower yields due to the establishment of the secondary population of sprangletop. If the problems are defined, costly errors and waste of precious time usually can be avoided.

The scope of problem solving should be limited. A common mistake involves initiating more research than can be carried out effectively.

Limit the objectives of each experiment. A single experiment will seldom, if ever, provide all the answers to a problem.

All new experimentation should be preceded by a thorough literature review. If necessary, use telephone or mail to personally contact other workers concerned with the same problem to acquire the latest information available. Knowledge of previous experience, not only indispensable in developing sound and useful experiments, also prevents needless duplication.



Results reported for work on a similar problem can serve as guidelines, but the data should be verified under local conditions.

When background information suggests that a weed control research program should include chemical methods, the investigator faces a two-step choice. First comes selection of the most promising materials —including combinations of compounds—for the particular problem, and elimination of totally unsuitable chemicals.

Secondly, the developmental stage of chemicals is also important with a choice of: a.) readily available commercial herbicides used for other crops, or being considered for use on the crop in question; and b.) experimental herbicides. The attrition rate among the latter is high, thus decreasing their usefulness for a research program aimed at developing practical recommendations. Also, under resource and time limitations, the urgent need for a solution may preclude their use. However, if time is ample or if available commercial products are totally unsuited for the problem, either early or advance stage experimental chemicals become a possibility.

When alternatives are limited, combinations of herbicides should be considered. Combinations compare favorably with individual herbicides.

TABLE 1-1

Possible Advantages of Herbicide Combinations

(1) increase spectrum of weeds controlled;

(2) improve consistency of control;

(3) increase the margin of selectivity to crops due again to lower application rates;

(4) decrease residue problems for subsequent crops;

(5) combine contact and residual action;

(6) reduce purchase cost associated with a single expensive herbicide;

(7) retard development of resistant weed species;

(8) possibly cause synergism, thereby reducing amount needed resulting in lowered cost.

Synergism, as well as antagonism and additive effects, can be seen under field conditions. Although true synergism is difficult to prove, there are instances where increased weed control occurs compared to what would be expected from a simple additive effect. Antagonism between different herbicides also exists; it can be due to chemical, physical, or physiological incompatibilities.

Increasing the spectrum of weeds controlled results from careful selection of the herbicides combined. A useful and frequently applied formula mixes a herbicide with particular effectiveness on grasses with one having strong broadleaf control ability. An increased margin of selectivity (or reduced toxicity to crops) stems from using lower rates of herbicides in combinations than for one herbicide used alone. Lower rates also cause less residue problem. Teaming herbicides with differing characteristics can provide both desired contact and residual activity.

WHICH HERBICIDES TO TEST

a. commercial herbicides

b. combinations of herbicides

c. experimental herbicides

1.2 TYPES OF FIELD TRIALS

An experiment should be planned according to objectives and based on available treatments, as well as previous research performed on the particular problem. Certain general trials can be designed to provide desired information most effectively. Trials tend to be recognized by name more than by a specific pattern, and the nature of the data collected may overlap considerably.

The levels of experimentation are:

—primary screening trials (multi-crop, multi-herbicide);

—secondary screening trials (mono-crop yield trials);

—regional and demonstration trials;

—special studies, including weed control systems.

FIGURE 1-1
Primary Screening Trial Layout

1.2.1 Primary Screening Trials

Mainly conducted by companies screening a large number of compounds and by a few universities, these trials are very early stage efforts to determine the activity level of a chemical toward specific species of crop and weed plants. Experimentation can take place in either the greenhouse (glasshouse) or field.

The most favorable conditions possible are desirable for this type of trial so the chemical can fully manifest its effects. The material is usually applied in a relatively wide range of rates to establish upper and lower limits of both selectivity towards crops and activity on weed species. Both preemergence and postemergence applications can be made, as well as incorporated and nonincorporated applications.

The choice of crop and weed species used in primary screening trials warrants careful consideration. A region's most prevalent or important crop and weed species should be included. Expanding the number of species to include representatives from other plant families also has utility in that a research worker can—with caution—extrapolate data suggesting possible susceptibility patterns of weed species. Perennial weed species should be excluded from primary trials.

The physical layout of a primary screening trial in the field usually requires planting long parallel rows of various crop and weed species. Chemicals being tested are sprayed in 1-2 m swaths at right angles to the rows. Both standard commercial herbicides—applied at standard field rates and representing important "families" of herbicides—and untreated "check" plots should be included among the trial's treatments.

All data obtained from the trial are subjective; that is, the performance of the treatments is evaluated but *not measured* by the researcher. The information, in essence, constitutes an estimate of performance and activity based on standards derived from experience.

Since evaluation of the trial is strictly qualitative, a nonreplicated study may be sufficient providing that the plot area is uniform and the trial well conducted. A minimum of two readings should be made for each plot (treatment), recording reduction in stand and reduction in vigor. Toxicity symptoms, if present, should be described in detail.

The primary screening trial will provide preliminary information concerning a chemical's crop selectivity

and its toxicity to weeds. Herbicides selected for further testing usually combine tolerance to one or more crops and toxicity to a broad spectrum of weeds. Exceptions have been made for herbicides that effectively control one serious weed species and few others (example: trillate and barban for control of *Avena fatua* L.).

Extrapolation may be useful when working with related species. For instance, a herbicide that proves to be safe on soybeans (legume) may be tested later for use in forage legumes. **Caution:** extrapolation should only be used as a guideline and not as a rule.

Herbicides toxic to most of the crop and weed species in the screening trial may be candidates for testing on perennial crops and for use as industrial nonselective herbicides.

1.2.2 Secondary Screening Trials

Herbicides, or combinations of herbicides, that perform well in early testing become candidates for secondary screening trials. This level of research aims at comparing the performance of experimental (or other) compounds on specific crops and weeds with established weed control practices in the field.

The choice of herbicides nominated for secondary trial work can be based on materials that showed promise in a primary screening trial, or on information supplied by either chemical-producing companies or other research sources. One or more of the herbicides commonly used on the crop under study should be included, whenever possible. Should the best commercial treatment be a combination of two or more herbicides, then each of the components should also be included in the trial as individual treatments. Weed free and unweeded/untreated check plots also provide useful comparisons.

Factors to compare among the various treatments are: yield; selectivity towards the crop; injury symptoms, their characteristics and persistence as the plants mature; weed control (both primary and secondary populations); and any shifts in weed population.

1.2.3 Yield Trials

Secondary trials specifically designated to test the effect of chemical treatments on crop yield—otherwise known as yield trials—take two forms. One is structured to assess the effect of the herbicide itself on the crop. Therefore, weeds not controlled by the treatment need to be removed by hand or by mechanical means to isolate effects of the herbicide from effects of the weeds.

In the second type of yield trial, weeds (those not controlled by the treatments) are allowed to grow so that the combined effect of competition and herbicide toxicity (if any) can be determined. Subjective data such as weed species controlled and herbicide symptoms can also be recorded from yield trials.

The number of separate treatments either can be reduced or the same as a secondary trial. The weed complex dictates the nature and number of treatments.

1.2.4 Regional Trials

These are conducted after secondary trials have provided enough basic information on a herbicide's performance to justify tests under more diverse conditions. Yield, injury symptoms, weeds controlled, population shifts, and soil residue information should be noted.

1.2.5 Demonstration Plots

After a compound has graduated from the basic screening and yield trials, it may be ready to display its performance—under local field conditions—to other researchers, extension personnel, farmers, and the general public. Demonstration plots are not research trials, although they can develop useful information.

Usually, demonstration plots consist of relatively few treatments, perhaps just two or three. One of these should be the standard recommended treatment, which may be an entirely different compound, for the crop or problem under attack.

The size of the plots should be large enough to allow proper demonstration of performance.

In some cases, regional trials can function as demonstration plots also, but care must be taken to avoid damage to the crops if harvest for yield data is planned.

1.2.6 Special Studies

As the name implies, special studies are designed to provide complementary but essential information on the performance of a herbicide. For example, tests could be undertaken to evaluate a chemical's residual activity in the soil, compatibility with other pesticides, or effectiveness in different formulations. Other examples include presence and extent of residue in plant tissue, amount of water carrier for optimum performance of a compound, and weed susceptibility (i.e., trials without a crop).

Other special studies do not involve herbicide performance in a given crop, but concern weed or crop competition, effect of other cultural practices and interactions on weed populations, effect of weeds on insect populations and diseases afflicting crops, and indirect effects of weeds on costs of production (i.e., insect control, moisture requirements, fertility requirements, increased cost of harvesting, and decreased return due to lowered crop quality). A few examples of special studies are discussed below.

A. SOIL RESIDUE STUDIES—The ideal herbicide for annual crops remains active only during the time between planting and harvesting. But there are few "ideal" herbicides and, in order to avoid problems, the residual activity of all herbicides must be determined under a variety of conditions. The most important environmental factors affecting soil residue are rainfall, soil moisture, soil texture, organic matter, and temperature.

Chemical residuality can be simultaneously tested in the field and greenhouse or laboratory. The mere presence of herbicide in the soil does not necessarily constitute a problem; however, a given concentration of herbicide in the soil may not manifest its toxicity unless specific stress conditions (drought, high temperature) occur.

A specific herbicide under test should be applied at a normal rate plus double, triple, or quadruple normal rate to establish a full range of effects. In the field, residuality can be estimated directly by planting susceptible plant species in each field plot at different times; or, soil samples can be removed from the plots periodically, transferred to the greenhouse, and used for growing sensitive plant species. A standard curve can be derived for each herbicide (tested in the greenhouse) by using the same soil with various known concentrations of the herbicide. A comparison of plants grown in known and unknown samples will generate a fairly close estimate of the soil residue.

An example of a hypothetical experiment to determine the residual activity of a herbicide in the field follows.

The same indicator species used in the field can be planted in the greenhouse in containers of soil collected from the field plots. Evaluation of root growth is possible also.

EXAMPLE 1-1
Residual Activity Experiment

plot size: 2 x 5 meters

replications: 4

layout:

plot	herbicide	rate*
1	atrazine	1
2	atrazine	2
3	atrazine	4
4	atrazine	8
7	check (unweeded)	0

sensitive species planted: cucumber, oats

data collected: percent germination/stand reduction

symptons (chlorosis/necrosis)

vigor

fresh weight 15-30 days after germination

note: no crop, other than test species, seeded in the experimental plots.

Highly variable environmental conditions can affect field experiments. This situation reinforces the necessity of complementary greenhouse experiments where temperature and moisture factors can be controlled. The effect of drought or temperature extremes (high or low) on the manifestation of toxicity in the bioassay (indicator) species should be noted.

Each treatment should be continued until a maximum of two, but preferably three, plantings show normal growth. Planting frequency will be determined by information available from the chemical companies as well as other research experience.

B. FORMULATION STUDIES—Different formulations, as the only variables, can be tested in an experiment. Comparisons should be made on the basis of equivalent doses (amount applied). The rates of material applied should be those that will not completely kill weeds in the test plot. Overly high rates can mask small, but important, differences in formulations.

C. VOLUME OF CARRIER STUDIES—The amount of water carrier needed for optimum performance is important, particularly for herbicides applied postemergence. In some cases volume needs to be critically low; for contact herbicides, higher volumes are required according to the amount of foliage to be treated. As with formulation studies it is necessary to

** Rate of application is usually expressed as kg ai/ha, kilograms of active ingredient per hectare. See section 2.12.9 for further discussion.*

use sublethal rates of the herbicide to avoid masking small differences due to volume of water.

D. COMPETITION STUDIES—Often there is need to assess weed competition magnitude and timing within the crop growth cycle both to justify weed control activities and to help determine feasible approaches to solving a problem. Weed competition experiments usually involve timing and frequency of weeding.

Experiments can take two approaches: keep test plots weed-free for a given number of days after crop planting, or allow weeds to grow and then remove them (and keep plots weed-free) a given number of days before crop harvest. Other treatments may include weeding from one to three times, according to the custom in the region.

TABLE 1-2
Various Weeding Treatments for a Short Season Crop such as Sorghum (Sorghum bicolor)

plot	*treatment*
1	0-10 weed-free days after planting
2	0-20 weed-free days after planting
3	0-30 weed-free days after planting
4	0-45 weed-free days after planting
5	0-60 weed-free days after planting
6	0-90 weed-free days after planting
7	weed-free
8	10 weed-free days before harvest
9	20 weed-free days before harvest
10	30 weed-free days before harvest
11	45 weed-free days before harvest
12	60 weed-free days before harvest
13	90 weed-free days before harvest
14	weeded all cycle
15	weed at 15 and 45 days after planting only
16	weed at 10 and 30 days after planting only
17	apply standard (commercial) recommended chemical treatment

Crop stand and vigor, and weed population (counts) are evaluated. Measurement of crop yield and assessment of crop quality are very important as well. An evaluation of harvestability can be recorded (just prior to harvest) using a 0-to-5 scale: 0 represents full access to the crop and no weed intereference, whereas 5 identifies an unharvestable crop due to weeds. Incidence of insects and disease may be evaluated also.

E. MISCELLANEOUS STUDIES—Greenhouse and laboratory studies can be carried out to determine the effects air temperature, soil organic matter (amount and nature), soil texture, rainfall and moisture, and other factors, have on herbicide persistence.

Experiments oriented toward cultural practice, excluding herbicides, can include parameters such as soil fertility levels, plant varieties, population densities (crop and weed), row spacing, shading effect, etc.

1.3 LOCATION OF TRIALS

Site selection is of utmost importance, particularly in off-station trials. The problems under investigation should exist at the selected site. Other physical elements—weed population, soil type, fertility, moisture and slope—need to be as uniform as possible.

These factors should be considered when planning experiments so that necessary adjustments can be made to compensate for less-than-desirable uniformity.

Trials can be located either on or off research stations depending on an experiment's objectives and the availability of land for plots. Usually early screening trials are conducted at research station facilities where crop injury and poor weed control can be tolerated, (i.e., causing no public concern). Stations may be operated by a government, university, commodity group, or private industry. Specific trials, such as studying the control of a particular weed species, may have to be conducted off-station. While most special study trials are conducted at a research station, the majority of regional and demonstration trials are not.

Although the bulk of initial investigation occurs at research stations, a new weed control measure cannot be considered for wide-spread usage until trials can be carried out under local farm conditions to assess the effect of temperature, soil type, weed species, local cultural practices, and other similar factors.

1.4 AGREEMENT WITH LAND OWNER

In establishing off-station trials, careful selection of a cooperating land owner, or manager, is crucial. Off-station plots are easily lost due to a number of causes, most commonly lack of proper communication between researcher and cooperator.

The cooperator must fully understand what cultural practices are to be followed and what the experiment's goals are. He should know his role in the experiment and should understand that injury to, or death of, the crop may result and that uncontrolled weeds may make some of the plots unsightly. If poor weed control causes damage or decreased yields, proper compensation should be made to the cooperator. Also, laborers need to be made aware of the trial and given very clear instructions as to their role in it.

Plainly visible markers help protect the trial. Since these are often lost, broken, or stolen, relatively fixed or permanent objects, such as trees, roads or fences should be used as reference points.

If yield data are needed, they are usually taken before the rest of the area is harvested. Many good trials are lost to over-anxious harvest crews. Fencing is required if livestock or wild animals will be grazing in the area. The trial also should be readily accessible. Even with the best of plans and security, a researcher can expect to lose up to one-half of off-station trials.

Agreement should be reached with the cooperating grower as to disposition of the treated crop. In some countries it is illegal to allow crops treated with experimental pesticides to be sold in the market. In this case the product should be purchased at a predetermined price and then destroyed.

1.5 LEVEL OF PRODUCTION TECHNOLOGY

The researcher has to decide whether to modify environmental conditions, and to what exent. For research to yield results that immediately benefit farmers in an area, resour-es must be used that are available to the farmer. Two examples follow:

(1) If farmers cannot obtain specialized machinery to incorporate herbicides, then incorporation during research should be performed as the farmer will do it. Perhaps a spike tooth harrow is not as effective as a rotary tiller, but it may be an adequate substitute when used properly.

(2) Some herbicides are highly dependent on adequate soil moisture. Research with these herbicides should be questioned in low rainfall, non-irrigated areas.

Circumstances may prompt the researcher to use the most advanced techniques even though the results are not immediately applicable.

Notes, references, etc.

2 Research Procedure

- ☐ *Select site*
- ☐ *Layout blocks*
- ☐ *Square and mark area*
- ☐ *Calibrate equipment*

2.1 ESTABLISHING TRIALS

After the planning stage has been carefully completed, the researcher is ready to initiate the experiment. The actual establishment of the trial and its subsequent development can take many forms, but the basic principles for all trials are the same. The method employed is up to the individual researcher. It must be kept in mind that research is costly in terms of money, effort, and time and that each experiment should be designed and conducted to minimize errors while simultaneously providing the maximum amount of information per unit of investment.

Quality of data depends on design and technique:
Poor technique — poor data.

All data should be recorded:
do not rely on memory alone.

Plans and Data should be recorded in duplicate:
keep the duplicates in a separate, safe place.

2.2 SITE SELECTION

As mentioned in the planning section, uniformity is a main concern when selecting a field experiment site. Maximum uniformity of weed numbers and species, soil fertility, soil type, and moisture contribute to reliable evaluation of treatments being tested.

Unfortunately, researchers usually confront nonuniformity of one or more important factors. Moreover, field research is often initiated on newly prepared seedbeds where differences are not apparent. Frequently, a compromise regarding uniformity, accessibility, and inconvenience to the farmer must be made. Roadsides, row ends, and field corners should be avoided as normally being least uniform.

Whether on or off a research station, trials should not be located on the site of a previous trial until at least one, and preferably two, years of uniform cropping have occurred. Most weed control research leaves nonuniformity of soil nutrients and weed seeds in addition to herbicide residues. Herbicides may remain in the soil at active levels for 6 to 19 months or longer depending on the herbicide, amount used, and environmental conditions.

2.3 BLOCK AND PLOT ARRANGEMENT

When a known gradient exists, such as a slope or change in weed species, the blocks should be placed *across* the gradient rather than following the gradient.

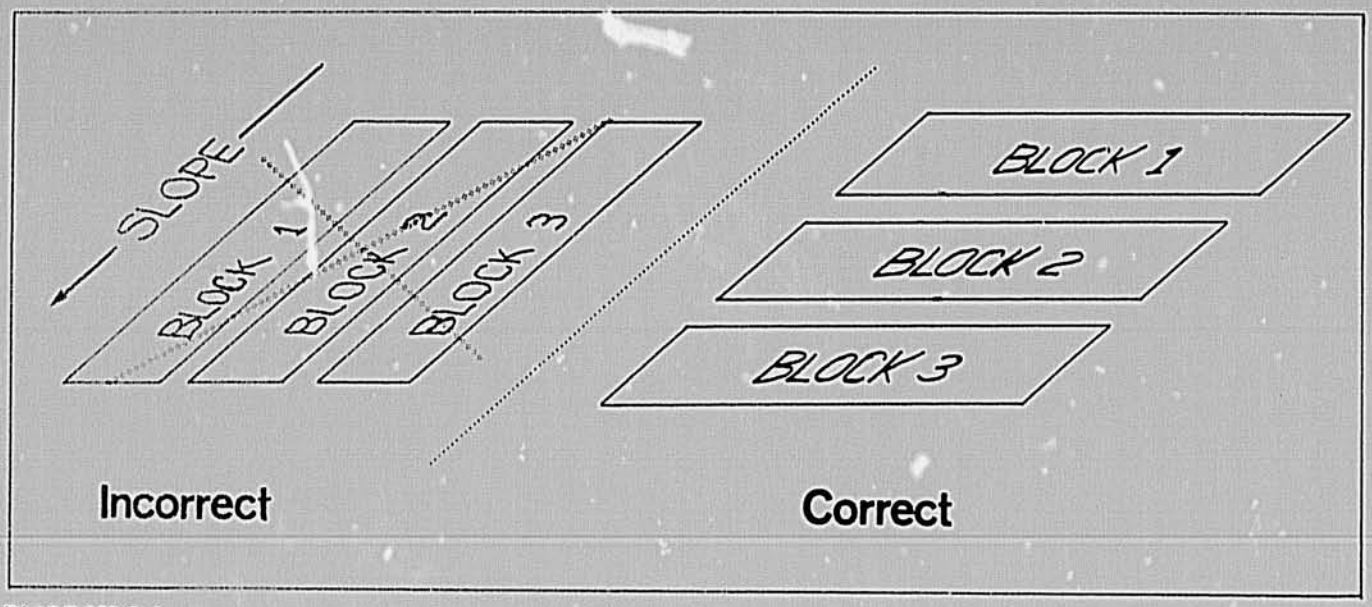


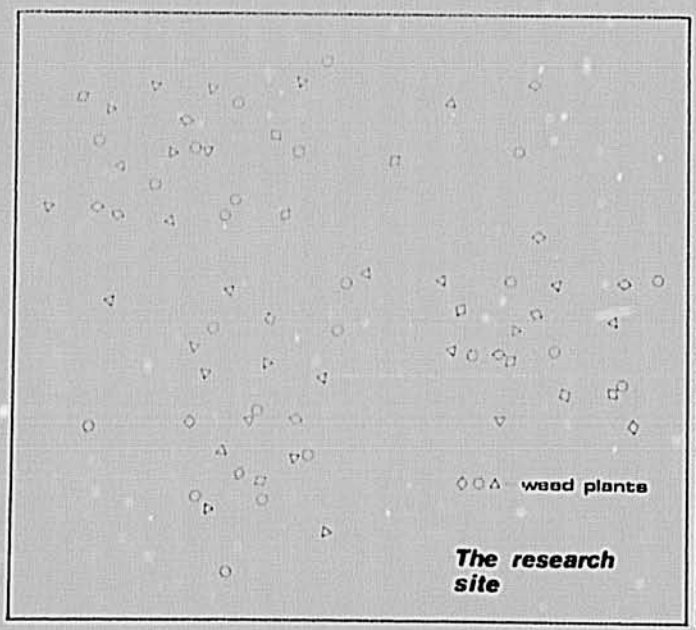
DIAGRAM 2-1

Problem: Gradient in fertility and moisture due to slope.

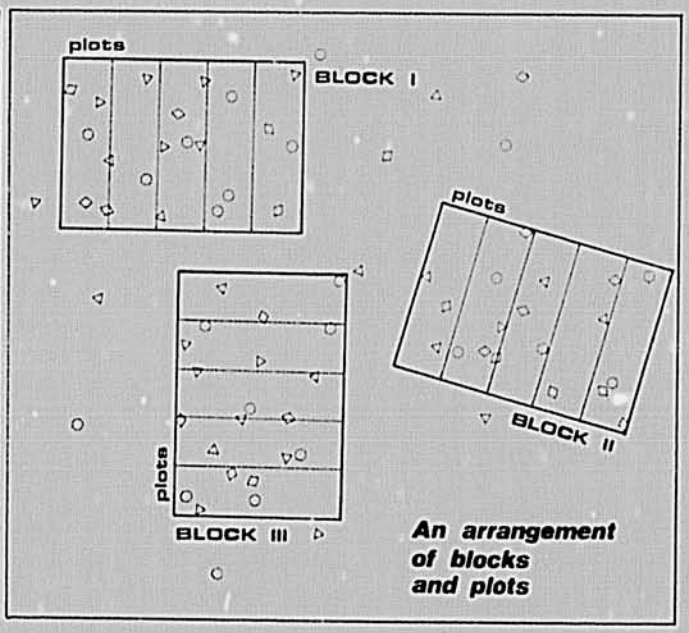
The goal in locating blocks is to have maximum uniformity within the blocks. Differences between blocks, although ideally kept low, can be accounted for in the statistical analysis of results.

A common misconception is that blocks must be located close together. If results can be improved by spreading out blocks within a field or even in different fields, it may be desirable to do so. Thus, regional trials in farmer's fields can be analyzed statistically by considering each location as a replication. This assumes, however, that the *relative* performance of the various treatments will remain the same and providing that climatic conditions allow a uniform harvesting.

Weeds tend to grow in concentrated spots, or patches, within an area. Blocks and plots should be arranged to achieve maximum uniformity both within and between the blocks, assuming that differences in soil fertility, soil moisture, and soil type don't constitute a serious problem.



The research site



An arrangement of blocks and plots

DIAGRAM 2-2

Problem: Establish plots and blocks in an area with patchy populations of weeds.

Field researchers are often faced with using an area of restricted size or irregular shape. Size and shape limitations need not be a deterrent to research as blocks and plots can be arranged in a variety of configurations to suit a specific area.

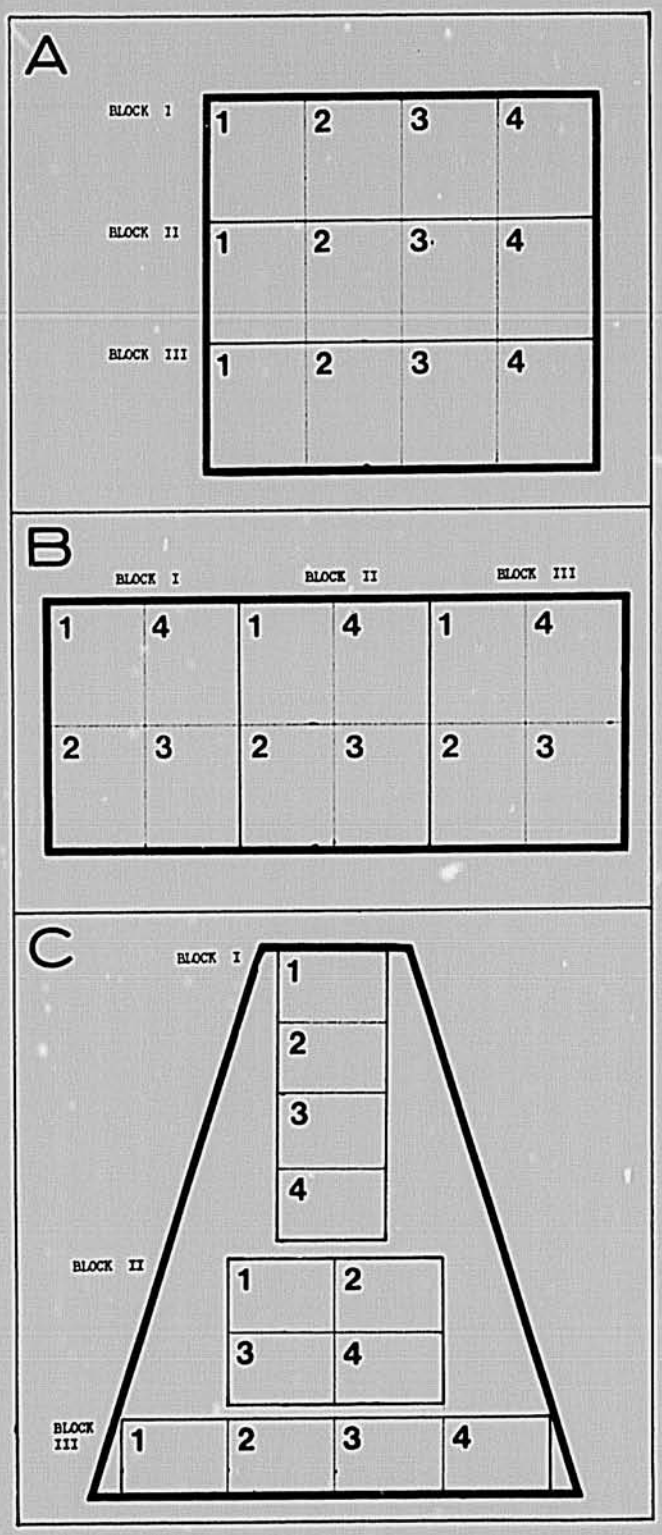


DIAGRAM 2-3

Examples of various block and plot arrangements for: 3 replications, 3 blocks, and 4 plots (treatments per replication).

A researcher can adjust a plot layout design before a trial is located on the ground when lack of uniformity is apparent. When preplant or preemergence herbicides are part of a trial, it is suggested that research blocks should be as square as possible. A *square shape* permits space for all treatments while minimizing the distance required in any one direction. The shorter distance will provide less chance, theoretically, for variations in weed population.

2.4 PLOT SIZE

Plots should be kept as small as possible, but still provide the desired information without excess variability. Consideration should be given to the following factors:

(a) **Objectives:** plots in screening trials can be smaller than in yield trials; demonstration plots are usually the largest.

(b) **Uniformity of weeds:** as uniformity improves, plot size can decrease.

(c) **Type of weeds:** creeping perennials require larger plots than upright annuals.

(d) **Type of crop:** cassava requires more area than rice or other small grains.

(e) **Equipment:** if only hand equipment is used, plots can be smaller than if mechanized equipment is used; planting, cultivation, incorporation, and harvest equipment also should be considered.

(f) **Cultural practices:** plot size may need to be adjusted to fit plant or row spacing or irrigation systems.

There may be instances where minimum plot size that will provide reliable data is difficult to determine. Analysis of results from a single year of experimentation based on a design of plots containing nested parcels (if previously recorded data are unavailable) can be useful.

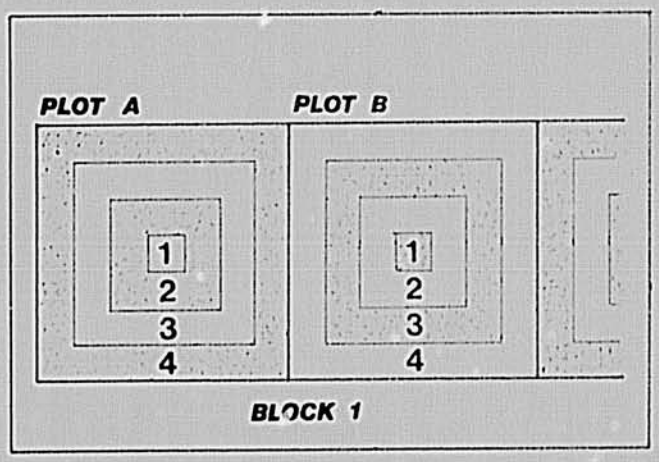


DIAGRAM 2-4

Plots with Nested Parcels to Help Determine Optimum Plot Size.

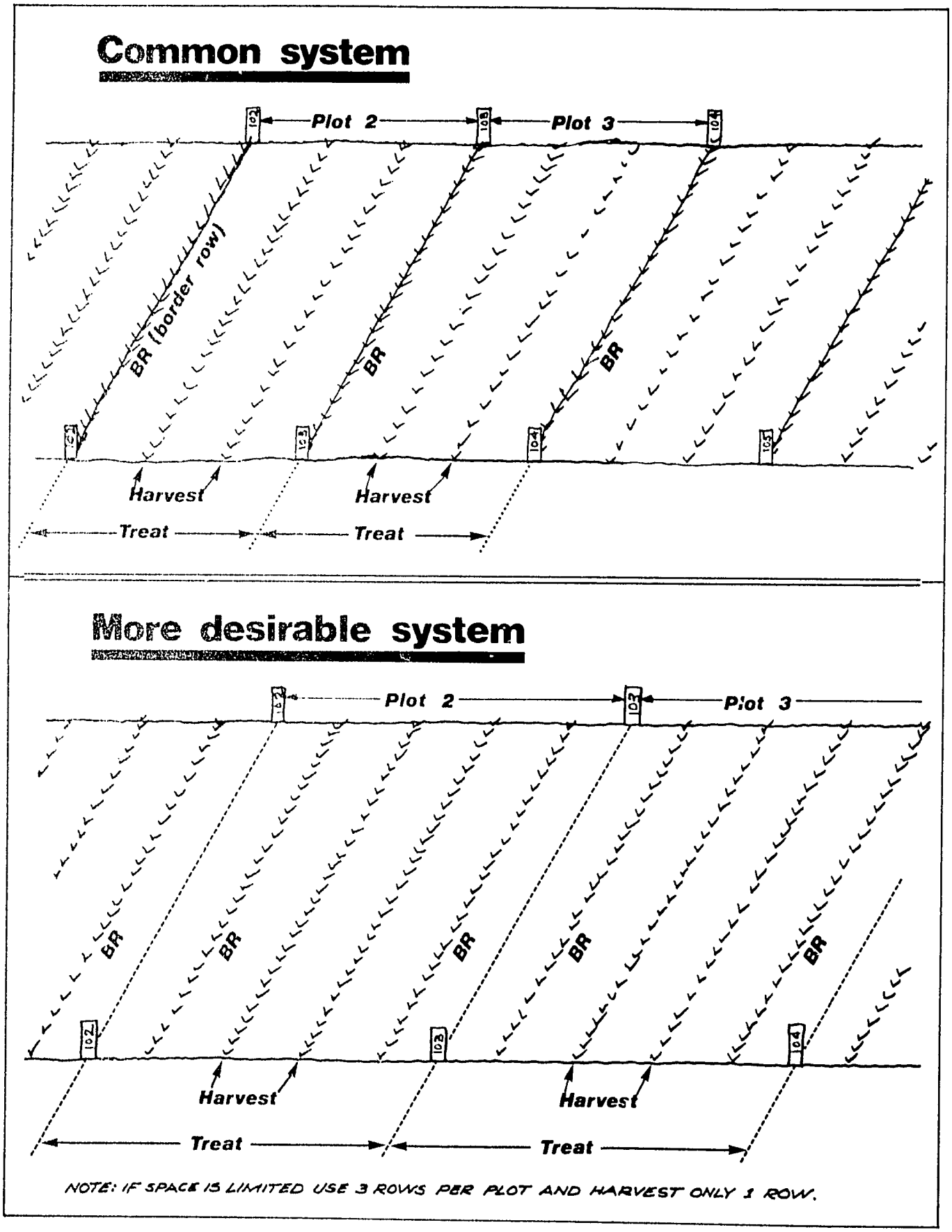


DIAGRAM 2-5

Establishing Borders in Row Crop Experimentation

Each plot (A, B, etc.) receives a different treatment. The results of parcel 1 from each plot are compared statistically, then the results of adding parcels 1 and 2 from all plots, then parcels 1, plus 2, plus 3, and finally the total of all parcels from each plot. The results of calculating the coefficient of variation for each parcel (or combinations) are then compared to suggest which plot size should be considered.

2.5 PLOT BORDERS

Borders constitute the transition zone between 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 the outside rows are not harvested.

A common method establishes plot boundaries along the center of a crop row; one row thus serves as the common border row for two adjacent plots. If space is available, a better system involves placing boundaries between rows so that each plot has a separate border row on each side (diagram 2-5).

In non-row crops (solid-seeded crops) a border area is also desirable. Usually this is accomplished by spraying the entire plot, but harvesting only a center portion.

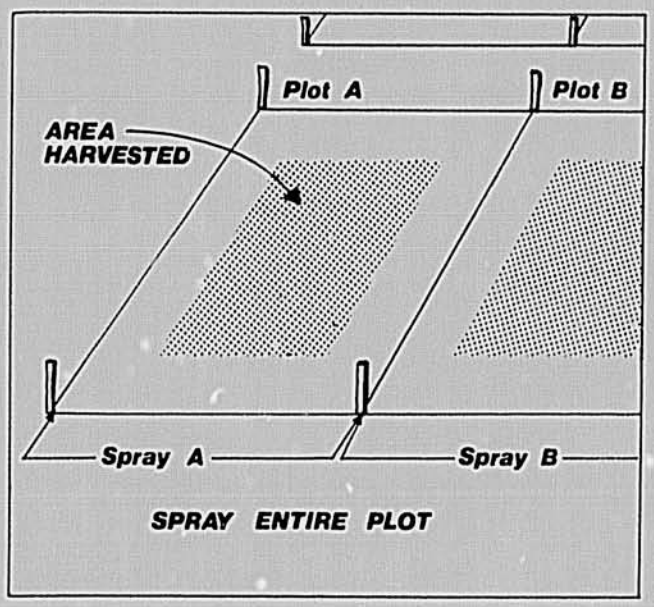


DIAGRAM 2-6

Borders in Solid-Seeded Crops

Some researchers prefer to leave an unsprayed zone between each plot to facilitate visual estimation of crop injury and weed control. However, an unsprayed zone may be undesirable because more area is required, weeds are not controlled, and yield is reduced. These aspects may be especially important for research conducted on a cooperator's field.

2.6 CONTROL PLOTS

Control treatments are usually:

(1) an untreated zone;

(2) a weed-free area;

(3) the common weed control practice for a region (manual, mechanical, etc.);

(4) standard, or currently used, herbicide treatment.

The untreated control, where weeds are allowed unrestricted growth, has utility for measuring degree of control and the gross effect of weeds. Since weeds usually are not permitted to grow completely unchecked in commercial fields, the method is just not commercially realistic, but can provide usable and even essential information.

FIGURE 2-1

An Untreated (control) Plot

The control which is kept weed free serves to determine any detrimental effect of a herbicide on a crop. Numerous timely manual weedings or cultivations may be needed, performed carefully to avoid damaging the test crop. Excess mechanical activity poses the hazard of yield reduction which can complicate or confuse interpretations of results.

A plot (or plots) given the commonly used manual or mechanical weed control practice for the crop being tested often provides useful information. The standard herbicide (if any) being used in the area should also be included to provide a basis on which to judge new herbicides.

2.7 HERBICIDE RATES

The nature of a weed control research exercise determines the rate(s) of herbicide application. The objective is to select that rate (or those rates) which will generate maximum information within the scope of a trial. In a screening trial, from three to five rates (rather widely spaced) may be used since exact rate data is either insufficient or non-existent. An early trial

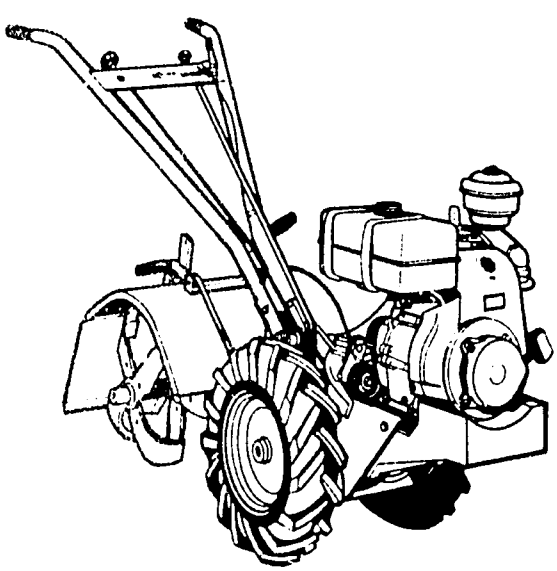
could be established with a variable rate (logarithmic) sprayer to identify promising rates.

When herbicide data are more plentiful, the number of rates can be reduced to two or three. If an approximate optimum rate is known, one lower and one higher rate could be used. And once a recommended rate is established, rates of two, four, and even eight times should be tested on a crop. Knowledge of a compound's upper limit of selectivity (non-effect) toward a crop is essential.

The double rate (two times the recommended rate) has special importance. It simulates the condition of overlapping spray applications; also, it can develop vital information if a compound's selectivity toward a crop falls in a narrow range, but does not manifest itself under normal conditions. Some herbicides have been fully developed for use in a crop before someone discovered that under adverse climatic conditions (drought or high temperature) selective rates narrowed. Including rates higher than those recommended helps determine the margin of safety.

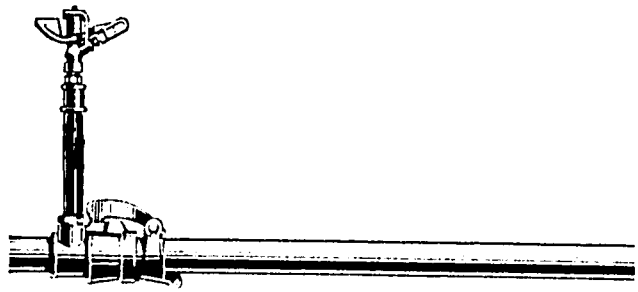
2.8 CULTURAL PRACTICES

Crop research consumes time and money. For these two reasons, as well as the fact that temperate climates usually have only one growing season per year, everything within reason should be done to assure that an otherwise useful trial is not wasted due to poor cultural practices. The best cultural practices commonly used in an area should be a minimum goal.



Uniformity should be stressed with all cultural practices. High quality seed of the recommended variety and proper plant spacing (density) should be used. Optimum fertility levels and uniform application are essential for sound crop growth.

In some areas irrigation is necessary, but crop production without irrigation is common. Some research stations located in rainfed areas nevertheless offer irrigation systems. If irrigation is used for herbi-



cide research under such conditions, it should be done only with a full understanding of the relationship between irrigation and herbicide performance.

Many research trials are planted by hand. More uniform conditions result from one person planting the entire trial; such a procedure is impractical for larger trials. The goal remains: each plot within one replication should be seeded exactly like its counterpart plots. One person could seed all of one replication or plant one or two rows across all of the plots.

To obtain a uniform crop population, direct seeded crops can be slightly overplanted and then thinned to the desired population at a very early stage of development. In transplant crops, such as cassava, missing plants can be transplanted into the trial after the experiment has begun. Great care must be taken before replanting to insure that the loss of plants was not due to toxicity of the herbicide.

2.9 SEEDING WEEDS

To assure uniformity and presence of certain weed species it is a common practice to plant weed seeds in a trial area, usually in one of four different ways:

(1) Evenly broadcast the weed seeds over the entire trial area (most common method).

(2) Plant weeds in rows just as the crops are planted, a method often used in early screening trials.

(3) Spread weed seeds as strips of different species within the crop itself.

(4) Spread weed seeds in strips separate from the crop.

Weeds growing separately from the crop are usually easier to evaluate or harvest, but the competition factor, often important in controlling weeds, cannot be observed. Except where weeds are planted in rows for screening trials, it is usually desirable to mix the seeds into the soil so that they do not all grow from one depth. Germination of weed seeds should be determined before planting so allowances for poor germination can be made, or new seed obtained. An unnatural condition results from planting too many seeds. When weeds are so crowded that they shield each other from the spray (canopy effect), or when delayed germination of even a small percentage of the seeds occurs, the herbicides will often give misleading results.

2.10 MARKING EXPERIMENTAL AREA

When an experiment's plots include trees or perennial shrubs, or are situated along roadsides or ditches, bright color paint can be used to mark plot location. Also, brightly colored corner markers may prove useful in protecting trials from unwanted cultivation, mowing, spraying, or other cultural practices, particularly in off-station trials.

Once the seedbed is prepared, the test area is measured and plot markers put in place. If the trial includes herbicides to be incorporated in the soil before planting (preplant incorporated), the trial corners should be marked (see squaring method, below) as well as the plots that will receive the incorporation treatment. Incorporation and seeding follow spraying (or granule spreading). The incorporation process involves stirring and mixing the herbicide into the soil thereby altering seedbed physical characteristics. There is a choice of methods to restore desired overall plot uniformity:

(a) the plots with incorporation can be rolled or otherwise firmed;

(b) all plots can receive the same mechanical (but not chemical) treatment.

NOTE: caution is required during incorporation to avoid spreading treated soil into adjacent plots.

The trial is now ready to be squared and then staked. Expensive transits, or a simple, easily fabricated sighting device can be used to square a trial. Even more useful and economical, a triangle with sides 3, 4, and 5 units long can be employed as a convenient and accurate method (based on the formula $a^2 + b^2 = c^2$).

Steps for using a 3 x 4 x 5 triangle to establish a 90 degree corner are:

(1) Lay out the front line from point **A** to point **D.**

(2) Measure 3 units (meters, feet, yards, or other) from **A** toward **D** and establish point **d.**

(3) Extend the measuring tape (string, rope, chain, etc.) from point **A** at an approximate right angle (90 degrees) to line **AD** to establish a temporary line **AB.**

(4) From point **A,** measure 4 units toward point **B** along temporary line **AB** and establish point b.

(5) Next measure 5 units from **d** toward **b** and move point **b** to either side of temporary line AB to give the full 5 units and create an exact right angle.

(6) Re-establish point **b** at the full 5 unit mark.

(7) Establish point **B** so as to exactly align with points **A** and **b.**

(8) Lines **AD** and **AB** are now squared with each other and the remainder of the trial can be laid out.

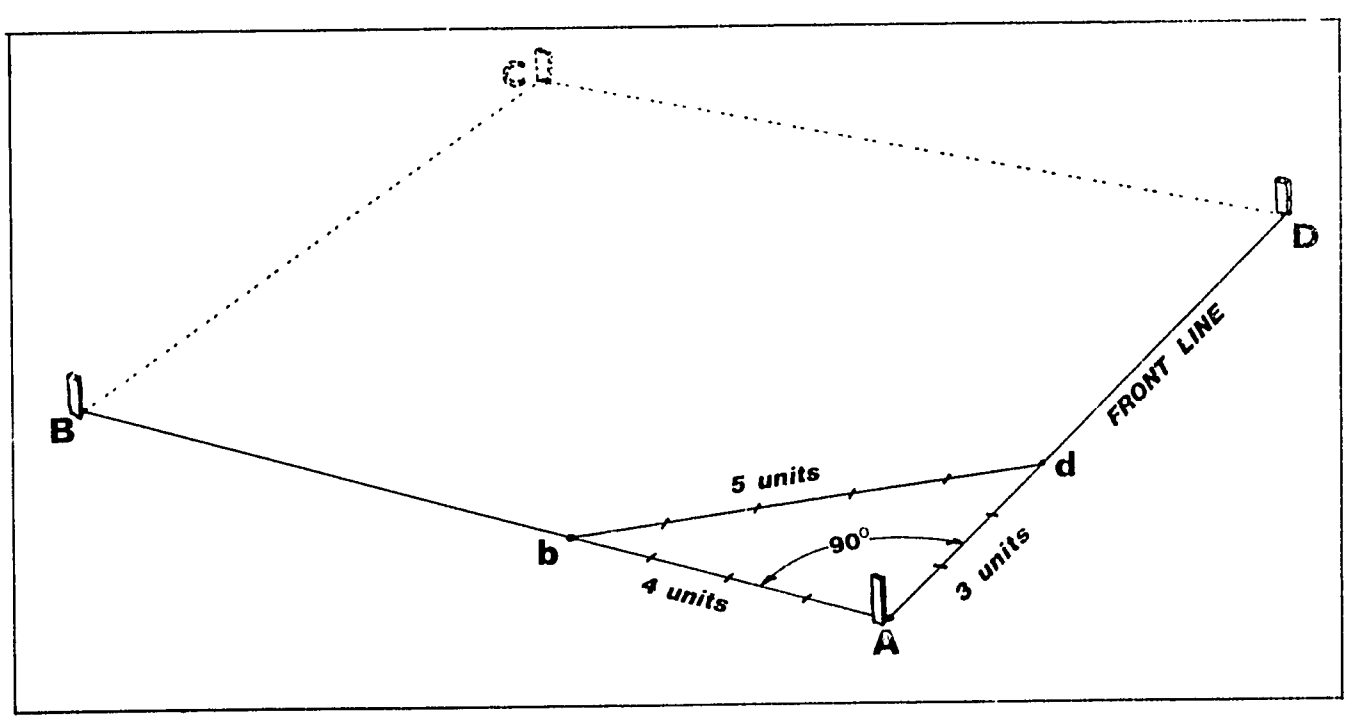


DIAGRAM 2-7

Using A 3 x 4 x 5 Triangle to Square Plots

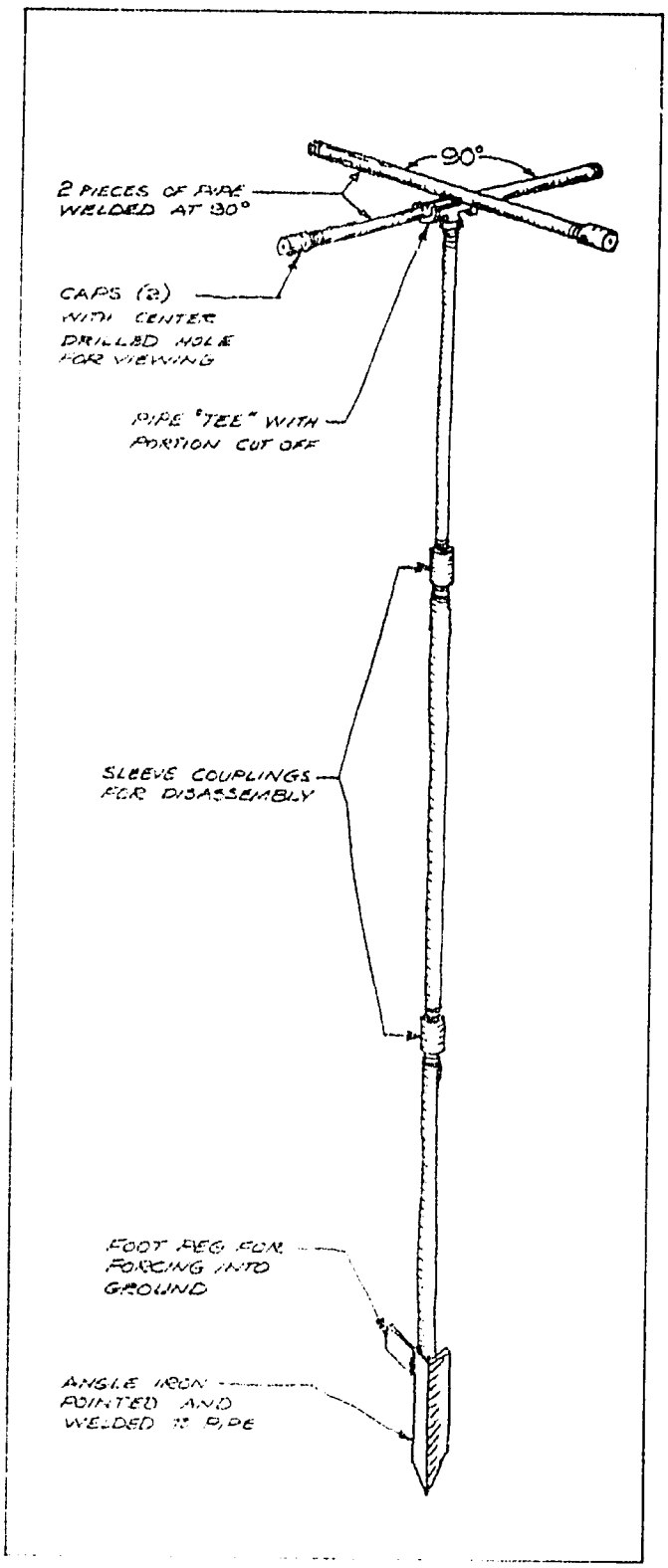


FIGURE 2-2

Simple Sighting Device for Squaring Plots

Plots are staked or marked for identification using wooden, plastic, metal, or wire markers. Wood is the first choice (of materials) because it will decompose if accidentally left in the field. In some cases (e.g., expecting numerous visitors to the plot area) it is helpful to attach labels to the markers listing plot number, treatment, rate, and time of application. Rain and sunlight cause deterioration and suggest use of permanent ink or water resistant paint, and, for paper labels, coating with melted wax after marking. If there is a chance of bias being introduced when the plots are evaluated, treatments should not be included on the label. (An alternative is to evaluate the plots from back to front without being able to see the labels.)

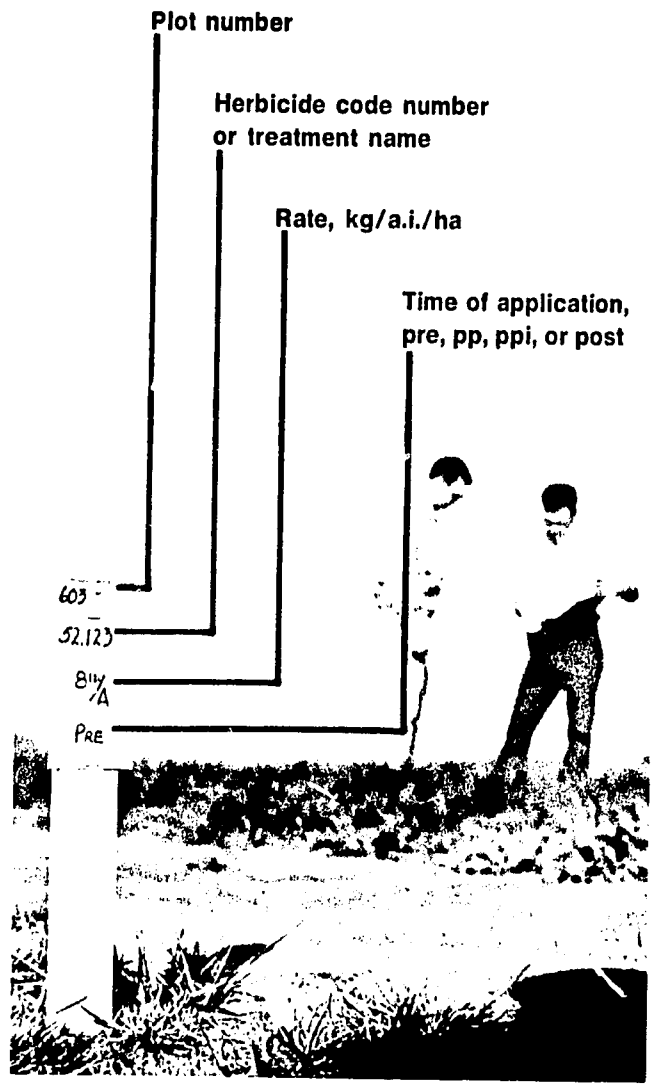


FIGURE 2-3

Plot Label for Demonstration Purposes or for After Evaluation

2.11 NUMBERING PLOTS

Perhaps, among all ways of numbering plots, the most useful can be described as follows: consider the first block as 100s, such as 101, 102, 103—etc. The second block will be 200s, the third, 300s, etc. The first digit always refers to the block and the second and third numbers refer to plot numbers.

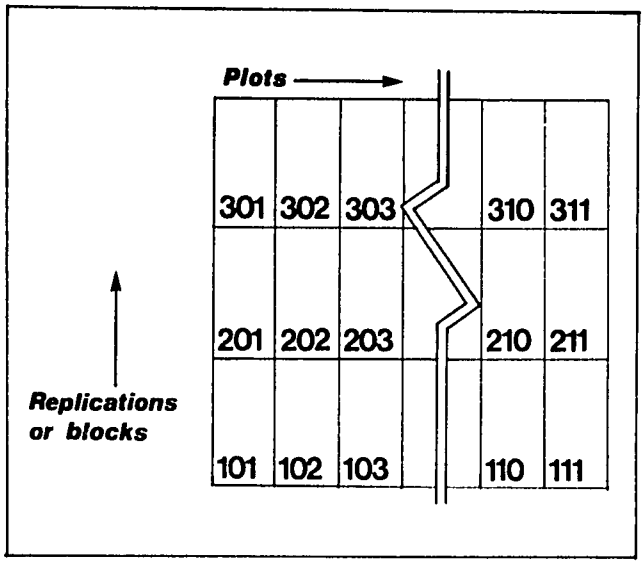


DIAGRAM 2-8

Example of Numbering Plots

Some researchers place numbers on plots at random as a means of randomizing treatments. This adds unnecessary confusion to an otherwise orderly process.

2.12 EQUIPMENT

In selecting application equipment, research workers need to be aware that each crop and herbicide may present a special problem. Availability, however, often determines which type of equipment is used.

Many different types and models of sprayers are available ranging from units specifically designed for research to those intended for commercial use. The more common types of applicators are manually pumped sprayers, compressed air or gas sprayers, logarithmic sprayers, and engine driven tractor mounted sprayers.

2.12.1 Manually Pumped Sprayer

Primarily for commercial use in areas of non-mechanized agriculture, this type of applicator is relatively uncomplicated, rugged, and dependable, important aspects in areas where repairs and replacement parts may be difficult to obtain. The person carrying the unit moves a lever arm up and down to actuate the pump. Continuous pumping maintains the pressure on some sprayers, whereas on other models pumping is minimal after achieving adequate pressure initially. Pressure chambers fitted to some models eliminate variations in pressure.

Most manually pumped machines deliver spray through a hand-held lance or wand to a single nozzle. Frequently sprayers are sold with a cone nozzle; it should be changed to a flat-fan or flood jet nozzle for spraying research plots.

FIGURE 2-4

Manually Pumped "Knapsack" Style Sprayer

A more uniform application can be achieved, when using a manually pumped sprayer with a single nozzle, by spraying the plot area several times. The second spraying should be in swaths perpendicular to swaths of the first spraying. Replacing the single nozzle with a two- or four-nozzle boom may be desirable to gain more uniform application on larger plots. A pressure regulating valve and a pressure gauge are also useful additions for research applications.

2.12.2 Compressed Air Sprayer

Although many compressed air sprayers are also hand pumped, the pumping is performed all at one time with the sprayer resting on a surface, not during actual application. There are also models that are designed to accept compressed air from a mechanical source again occurring prior to actual spraying.

Components include a metal or plastic tank (with capacities generally in the range of 3-10 liters), manually operated pump with "D" or "T" shaped handle and plunger, discharge tube, hose, control valve, wand/lance, and nozzle or boom. Most models are delivered with a cone nozzle which should be changed to a flat-fan or flood jet nozzle for spraying most research plots.

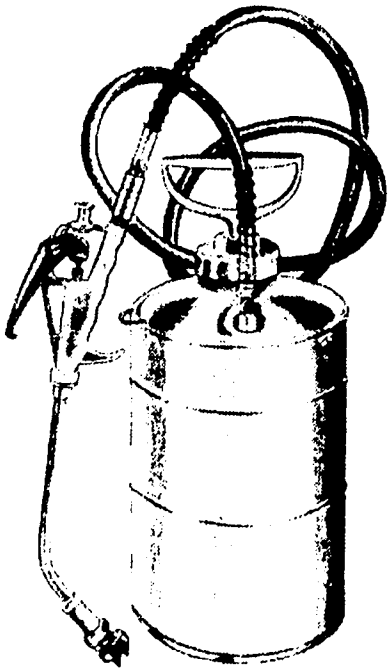


FIGURE 2-5

Compressed Air Sprayer

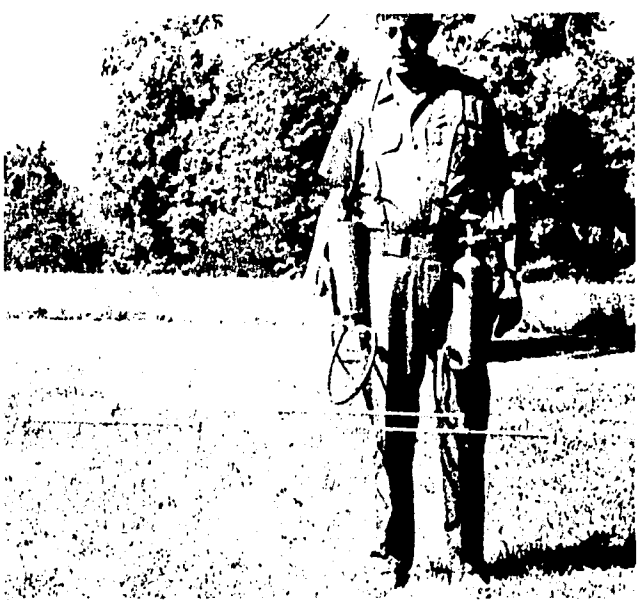


FIGURE 2-6

Manually Carried Compressed Gas Sprayer

Pressure is built up in the spray solution holding tank before starting to spray. Since this type of sprayer is not pumped while spraying, it operates most efficiently when no more than two-thirds full of liquid. This produces enough air capacity to spray normal sized plots and also to prevent sudden pressure drops. The pressure drops are greatest when the ratio of liquid-to-air in the tank is greatest; small volumes of liquid and large volumes of compressed air minimize pressure drops. A pressure regulator can be added to prevent fluctuation in output.

The hand-pumped, compressed air sprayer is the simplest sprayer used in research. It is inexpensive, usually easy to maintain, and commonly sold for home and garden use. It can be utilized to conduct effective research if its limitations are kept in mind.

2.12.3 Compressed Gas Sprayer

Sprayers using compressed CO_2 or nitrogen as a spray propellant have been developed for pesticide research. They provide rapid spraying (no pumping required), plus the advantage of constant pressure.

Basic components, in addition to a spray delivery system of tubing and nozzle (or nozzles), include a steel cylinder, pressure gauge, and regulator for the compressed gas. Herbicide solution is carried in a glass or metal container; glass bottles must be enclosed within a metal container to protect the operator.

The few moving parts of these sprayers keep their required maintenance minimal. Nonetheless, they should be kept in first class operating condition. Although cylinders (for gas) are relatively expensive to purchase, the gas itself is not. One or two refillable cylinders are sufficient for average size trials.

2.12.4 Bicycle Wheel Sprayers

These applicators have spray tanks, hoses, booms, pressure regulators, line strainers, and controls mounted on a simple framework supported by one or two bicycle-style wheels. Bicycle wheel sprayers

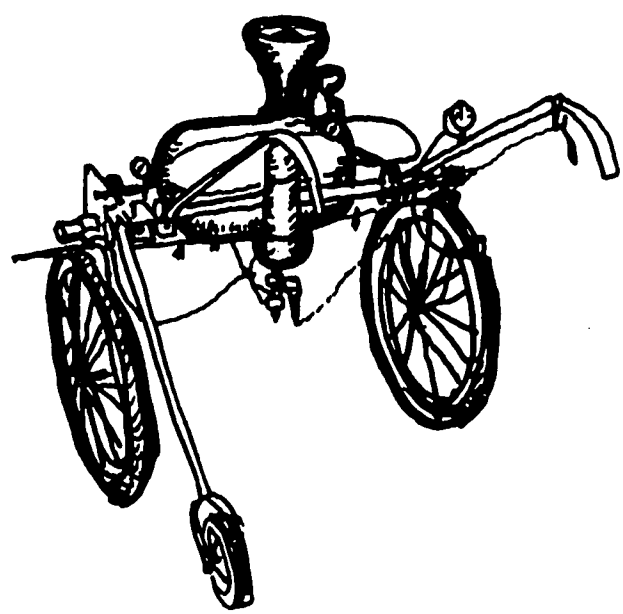


FIGURE 2-7

Bicycle Wheel-mounted Compressed Gas Sprayer

are very satisfactory for use on smooth ground, but difficult to use on rough ground or sandy soil. They facilitate keeping a constant height of the boom above ground level, but are more expensive and difficult to transport than either manually pumped or compressed air/gas sprayers. The wheeled type sprayer is useful for spraying larger plots because of its increased capacity and wider boom. Two wheels provide stability on smooth ground, but a single wheel is much easier to push and hold level on rough or sloping land.

2.12.5 Engine Driven Tractor Mounted Sprayers

Tractor sprayers are usually best suited for larger plots. The pump is operated by a small auxiliary engine on the sprayer, or by the tractor engine through a power take-off shaft. A few tractor sprayers used for research use compressed air to propel the spray. Several tanks can be mounted so more than one treatment can be applied in one pass over a plot or plots.

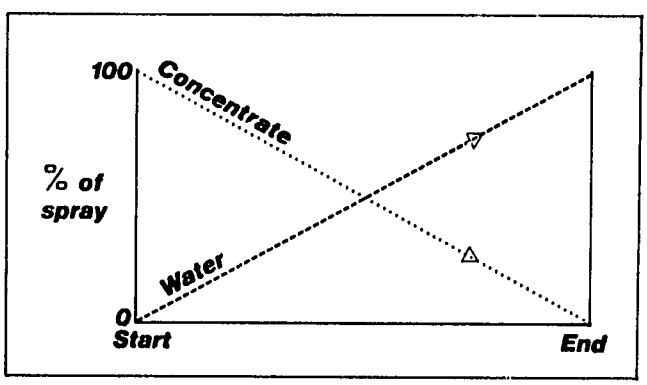


DIAGRAM 2-9

Water and Concentrate Percentage of Spray Applied by a Logarithmic Sprayer

2.12.6 Logarithmic Sprayers

The logarithmic sprayer is used mainly for initial screening of herbicides when a variable, or decreasing, dosage is desired. It is often used to determine specific rates in primary screening trials. This type of sprayer is equipped with two tanks, one for concentrate and the other for diluent. The desired starting concentration is prepared and placed in the concentrate tank, (i.e., the high rate of the herbicide); the concentrate is diluted on a logarithmic scale during application until only diluent is left in both tanks. Assuming perfect mixing, the half dosage time in seconds (D½) is given by the formula:

$$\frac{0.7\ Vo}{V} = D\ 1/2$$

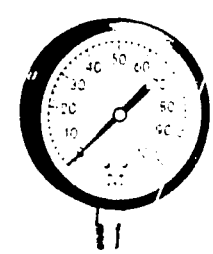
where Vo = volume in concentrate tank in ml.
V = output of sprayer in ml/sec.

Logarithmic sprayers are used commonly to apply material to single long rows of a few species to determine a new compound's optimum dosage range. The specialized nature of the logarithmic sprayer, however, precludes its wide use in most non-industry research.

2.12.7 General Comments on Equipment

A. AGITATION—Herbicide mixtures require agitation to ensure that material does not settle out of the "tank mix" during application. This is especially important when working with wettable powders. Since most sprayers used for small plot research lack mechanical agitators, it is imperative that the herbicides be well mixed when first placed in the sprayer tank. This means that there cannot be a long delay between mixing and spraying. Even so, a thorough agitation just prior to actual spraying is recommended.

B. PRESSURE GAUGES AND PRESSURE REGULATORS — All spray applicators need to be fitted with an accurate pressure gauge and pressure regulator in order to attain correct spray delivery. Pressures used for applying herbicides generally range from 0.7—2.8 kg. per cm² (10-40 lbs. per in.²). For an applicator with a multiple nozzle, wide swath boom, a second drop can occur between pump and nozzles.



C. HOSE AND BOOM—A sprayer's conduction system—the tubing, hose, etc., conducting spray from tank to nozzle(s)—should be durable, but also light weight. Inside diameter should fall between 0.5-1.5 cm. Polyethylene or metal, such as aluminum, copper, or stainless steel, can be used, but not rubber which tends to absorb chemicals.

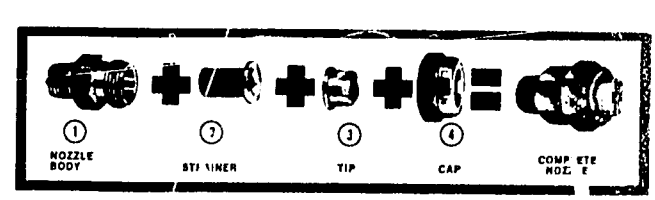


FIGURE 2-8

Components of a 4-part Nozzle

D. NOZZLES—Though nozzle requirements may differ from one application to the next, the basic functions of all nozzles are the same: to atomize or break

up liquids into droplets and disperse these droplets into specified patterns, and to determine flow rate in conjunction with pressure in the system.

Nozzles are constructed of either brass, aluminum, plastic, stainless steel, or nylon. Accuracy is usually satisfactory with all new nozzles; however, resistance to wear depends upon the material selected. Aluminum, plastic, and brass will wear rapidly if used to spray wettable powders or other abrasive materials. Nylon, stainless steel, and other specially processed nozzles are wear resistant to varying degrees. The most resistant are usually the most expensive. All nozzles experience wear when used and need to be inspected periodically; excessive wear changes the delivery pattern and rate.

Besides wearing out, nozzles are easily plugged by debris. Nozzles should be cleaned with a soft brush (an old toothbrush is useful) and not with hard objects such as wire or knives, particularly when the nozzle is made of brass or aluminum.

For herbicides, the most commonly used spray patterns include the flat-fan and flooding type for broadcast application, even flat-fan for band applications, and off-center nozzles for directed applications.

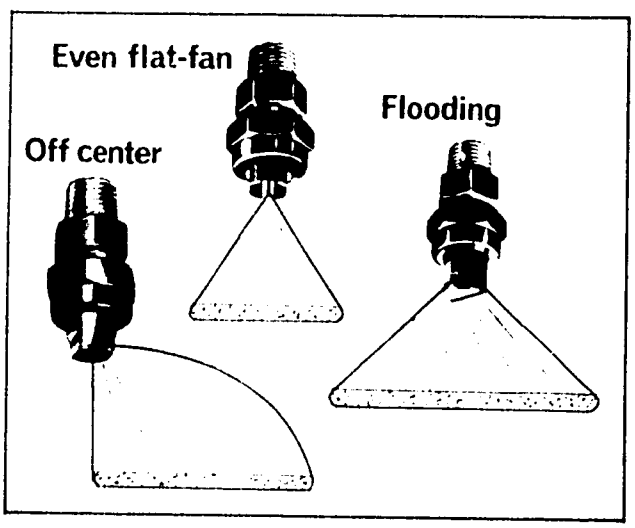


FIGURE 2-9

Various Types of Nozzles

Nozzles, even within a given spray pattern, can be obtained with various spray delivery angles. With the flat-fan pattern and even flat-fan pattern nozzles, the most commonly used angles are 65 degrees, 73 degrees, and 80 degrees. Flooding nozzles are more frequently used at wide angles up to 137 degrees.

Wider angles of spray delivery for boom-mounted nozzles permit a lower boom height (distance above the target surface) to obtain full coverage, with the important plus of shortening spray travel and reducing exposure to wind. Research spray work can be performed conveniently with a relatively short boom and

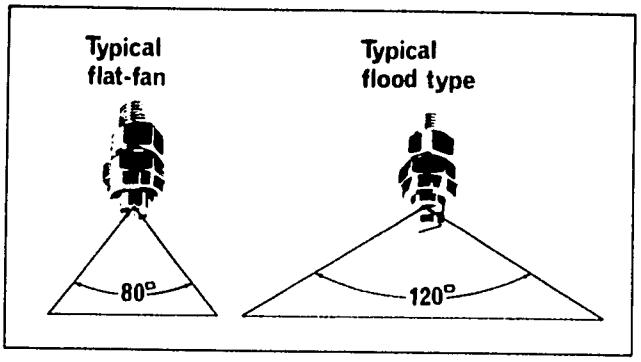


FIGURE 2-10

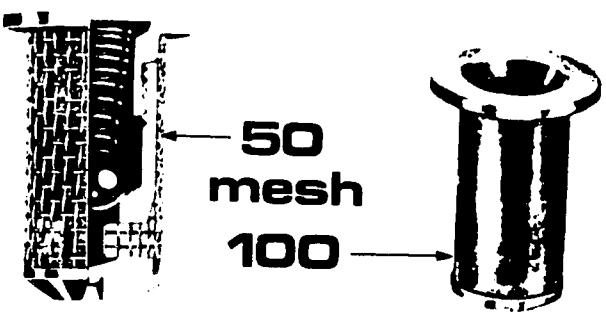
Angle of Spray Delivery

80 degree flat-fan nozzles. The boom can be kept relatively close to the target surface with this arrangement, thus reducing drift hazard while giving a uniform distribution of spray material over the entire length of the boom.

Narrow angle nozzles are used when the boom needs to be higher (or further from the target) to avoid growing plants, or when the terrain is very uneven.

The wider-angled flood nozzles are used rarely for research spraying except as a single nozzle fitted to a manually pumped sprayer.

E. NOZZLE SCREEN—Since foreign matter can easily plug the small orifice in nozzle tips, a screen should be placed behind the nozzle tip to help reduce nozzle plugging. There are two sizes of screens commonly available: 50 mesh and 100 mesh. Mesh size refers to the number of holes per linear inch: a 50-mesh screen has 2500 holes per square inch. For most



herbicide spraying, the 50-mesh screen is satisfactory. Many wettable powders will not pass through a 100-mesh screen, so it should be used with only very small nozzles spraying liquid formulations. NOTE: nozzle screens also can be referred to as nozzle strainers as in figure 2-8.

Nozzle dribble and dripping must be kept to a minimum—or eliminated, if possible—in small plot research. Nozzles may dribble liquid after flow to the boom has been shut off. A nozzle screen incorporating a check valve will help to eliminate dribble without

otherwise affecting the operation of the sprayer. Care must be taken to make certain that the ball in the check valve does not become jammed and that soil or chemical particiles do not hold the ball off its seat.

F. NOZZLE OVERLAPPING—Only two nozzle types—the flat-fan and flood type—are designed to have an overlapping pattern. The even flat-fan and off-center nozzles are not designed for overlapping patterns; even flat-fan nozzles are best suited for band applications, while off-center nozzles are for directed spray patterns. When possible, tips of overlapping nozzles should be oriented at a slight angle to prevent overlapping spray patterns from hitting each other and possibly causing excessive dripping.

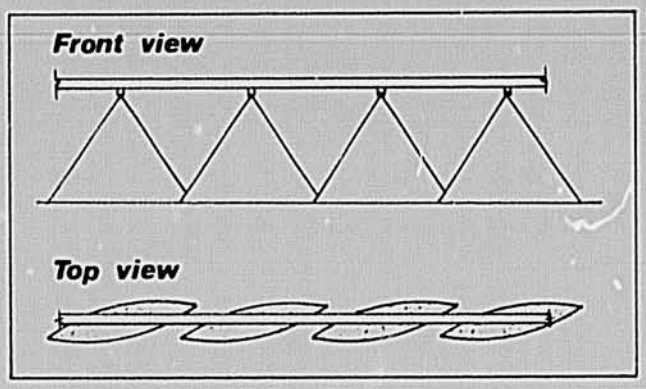


DIAGRAM 2-10

Nozzle Orientation—Overlapping Spray Pattern

Doubling the number of nozzles produces a "double overlap" or "double coverage" system. Under ideal conditions this arrangement double covers the target area. However, the system is designed for less than ideal conditions (i.e., rough terrain or uneven weed height) to ensure application of at least one-half the desired rate to all areas.

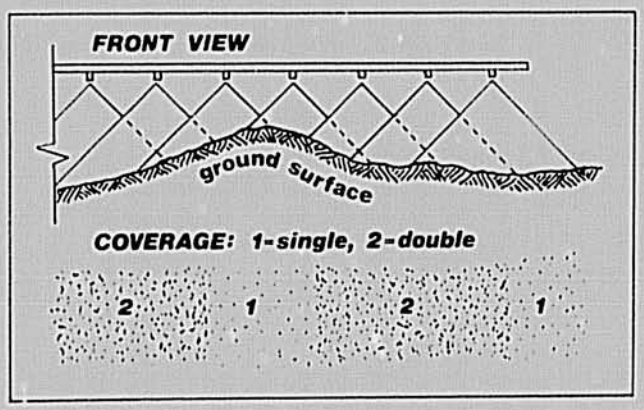


DIAGRAM 2-11

Double Coverage System for Less-than-Ideal Conditions

If wind is not a problem, double-overlap can be obtained by raising the boom to double the height required for single coverage. Any "double spraying" system should be used with caution on postemergence applications; the increased volume of water may reduce the herbicide performance.

G. EFFECT OF PRESSURE—Pressure regulators control the pressure of spray liquid at the nozzle. Most small, manually operated application equipment does not include a pressure regulator; small, inexpensive regulators can be obtained and attached. In the event of having to use an applicator without a pressure regulator to spray research plots, it is helpful to remember that a high volume of air in relation to the volume of liquid will produce the minimum rate of pressure drop.

If for any reason the pressure changes, the application rate will change, but not in direct proportion. *The relative change in delivery is proportional to the square root of the relative change in pressure at the nozzle.* Pressure must be increased fourfold in order to double output.

Pressure and nozzle orifice size determine droplet size. Higher pressures produce smaller droplets with greater risk of drift.

H. CHANGING OUTPUT—To change the rate of spray output, it is far better to change nozzle size and travel speed (terrain permitting) rather than to change pressure. For example, to double the volume discharged, either travel speed could be reduced 50 per cent, or nozzles with orifices twice as large could be used. Doubling the pressure would cause only a 43 percent increase in discharge for the case illustrated in Table 2-2.

TABLE 2-1

Effect of Forward Speed on Spray Output

kilometers per hour	*liters per hectare*
2	800
4	400
8	200

TABLE 2-2

Effect of Nozzle Size and Pressure on Spray Output

PRESSURE		1.5 KGM/cm²	2.8 KGM/cm²
		DISCHARGE LITERS/ MINUTE	DISCHARGE LITERS/ MINUTE
Nozzle size	8001	0.265	0.380
	8002	0.535	0.780
	8004	1.060	1.520

43% change due to pressure
100% change due to nozzle size

2.12.8 Application of Granular Herbicides

Application of granular herbicides often presents a problem to researchers since only a small proportion of herbicides are used as granules and since standard research application equipment is not readily available. Lawn fertilizer applicators have been used, adding sand or other suitable material as a diluent to obtain a more uniform distribution. Holes can be punched in the lids of small containers for spreading herbicides evenly.

Uniformity of application is critical and thereby a common source of error when testing granular formulations.

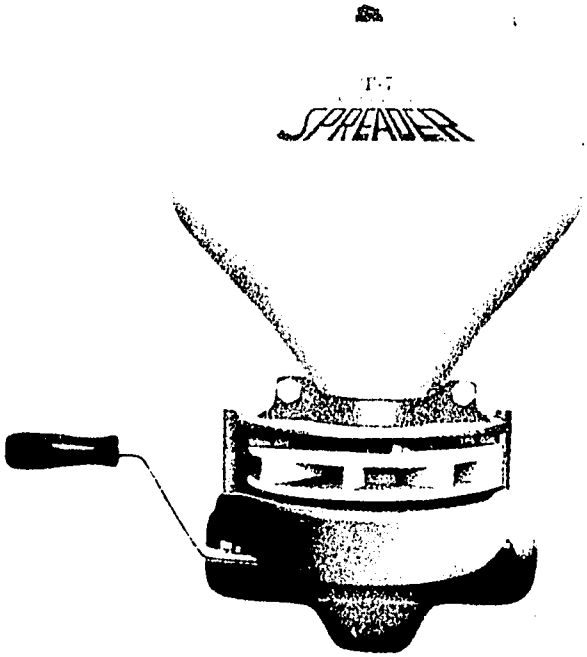


FIGURE 2-11

Manually Operated Granule Applicators

2.12.9 Calibration and Calculations

The method of applying herbicides to research plots will be determined by formulation of the chemicals involved (i.e., liquid or granular) and the application equipment available. A researcher should feel free to select the method and equipment best suited to a program's needs so long as accuracy and uniformity are assured. A critically important facet of minimizing experimental variability concerns accurately calibrating application equipment. Small research plots magnify minute application errors. As an example, a desired rate of 3 kg of material per hectare based on a 10 m^2 plot becomes 3.3 kg per hectare if inadventently applied to only 9 m^2, or 2.7 kg per hectare when applied to an 11 m^2 area.

There are two general approaches to, or methods of, applying herbicides: area basis and volume basis. Calculations for the amount of herbicide needed will be based on the application method chosen.

A. AREA BASIS—The area of the plot, or plots, to be sprayed with a particular material at a predetermined rate forms the keystone of this system. However, should less than the full plot width be sprayed, the area actually sprayed supercedes the full plot area in calculating amounts.

Note: A small amount of liquid is sprayed at the beginning edge of (but outside) each plot to be sure that all lines and the boom are full and that all nozzles are operating properly. An additional amount is left in the boom and hoses at the end of the plot. Allowances are made by adding a predetermined amount of water and herbicide. With the area system, this step amounts to simply factoring additional area into the calculations. The added area should always be the same for a given boom, regardless of plot size, being based on the extra liquid needed to fill that boom and to check nozzle operation. This method is most satisfactorily used with a spray tank shaped to allow discharge of all the liquid.

Using a predetermined area size permits all calculations to be made in advance. Dry herbicides should be weighed into bottles, plastic bags, or paper envelopes in the herbicide storage area, because most balances do not function well under field conditions. Liquid formulations either can be measured in advance

or measured from original containers in the field immediately prior to application.

EXAMPLE 2-1

Material: atrazine
Rate: 2 kg active ingredient/ha
Plot size: 2 x 5 m
Replications: 3

Calculations:

(1) Plot size—2m x 5m = 10m² x 3 replications = 30m²
(2) Add 1.5 m² to allow for filling boom and hose
(3) One hectare (10,000m²) requires 2000g active ingredient. 31.5m² requires X g

(4) $X = \frac{31.5 \times 2000}{10{,}000} = 6.3\text{g active ingredient}$

The commercial product required if the formulation is an 80 per cent wettable powder will be:

(5) in 100 grams commercial product there are 80g active ingredient;
(6) in X grams commercial product there are 6.3g active ingredient;

(7) $X = \frac{6.3 \times 100}{80} = 7.8\text{g atrazine commercial product.}$

Caution: The above example assumes the herbicide and water for all three replications are mixed together. **When spraying wettable powders, each replication should be MIXED and SPRAYED SEPARATELY unless great care is taken to prevent the herbicide from settling to the bottom of the tank.**

Greater accuracy is also required when all replications are mixed together: any error in application rate will not be noticed until the last plot of the series is sprayed. This is especially serious if all the spray is used before completing the last plot.

The amount of water required to cover the area to be sprayed can be determined by filling the sprayer's tank with clean water (only) and spraying the area at the desired pressure and speed and measuring the amount of water consumed. The operator should then pace himself by applying the measured amount of water to a non-plot area having the same size, surface, and walking conditions as the actual plot. Pacing requires several passes until the correct amount of water can be sprayed each time, making sure to actually begin spraying at the beginning of the pacing test and to stop spraying precisely at the test end as will be the case in applying herbicide to the plots.

B. VOLUME BASIS—With this method the amount of herbicide is calculated for a given amount of water rather than for a certain area. The volume of water used usually exceeds that required to spray the plot or plots; consequently a method should be devised to assure a constant and accurate speed. A stop watch serves this purpose. The volume method is useful when plots are large enough to require refilling the spray tank and when the spray tank design prevents using all of the liquid. There does not appear to be any other advantage in spraying small plots by this method.

The first step requires calibrating the sprayer to determine the output of water. A very convenient method of calibrating a small plot sprayer is described by L. Kasasian in his book, Weed Control in the Tropics:

> *"Pour a measured amount of water in the sprayer and spray 100m² exactly as if one were applying herbicide. When this is done, measure the amount of water left, and by subtraction, calculate the amount used. Then multiply by 100 to obtain the volume rate per hectare."*

EXAMPLE 2-2

Assume: sprayer applies 200 liters of water/ha
Total plot area: 3 plots, 2 x 5 m each = 30m²
Solution: use proportions

$$\frac{\text{liters/ha}}{\text{m}^2\text{/ha}} = \frac{\text{X liters}}{30\text{m}^2} \quad \frac{200\text{ liters}}{10{,}000\text{ m}^2} = \frac{\text{X liters}}{30\text{m}^2}$$

$$X = \frac{200 \times 30}{10{,}000} = 0.6\text{ liters for 3 plots}$$

Since 0.6 liters is the exact amount of water needed to spray 30m², the researcher might decide to use one liter as the total volume for each three plot series. The remaining 0.4 liter is used to check the nozzles and allow for error. The amount of herbicide can then be calculated for one liter.

EXAMPLE 2-3

Compound: atrazine
Desired Rate: 2 kg active ingredient/ha
Total plot area: 3 plots, 2 x 5 m each—30m²
Assume: sprayer applies 200 liters of water/ha

$$\frac{\text{grams/ha}}{\text{liters/ha}} = \frac{\text{x grams}}{\text{liters/30m}^2} \quad \frac{2000\text{ grams}}{200\text{ liters}} = \frac{\text{x}}{1\text{ liter}}$$

$$X = \frac{2000 \times 1}{200} = 10\text{ grams active ingredient}$$

The commercial product (c.p.) required if the formulation is an 80 per cent active wettable powder can be calculated as follows assuming 100 grams of c.p.:

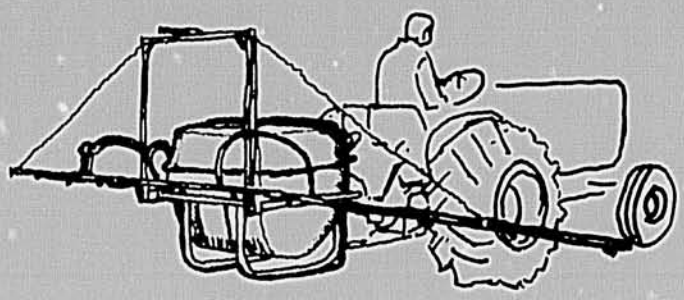
100 grams c.p. = 80 grams active ingredient

$$\frac{\text{grams of commercial product}}{\text{grams of active ingredient}} =$$

$$\frac{\text{x grams commercial product}}{\text{10 grams active ingredient}}$$

$$\frac{100\text{ grams}}{80\text{ grams}} = \frac{X}{10\text{ grams}}$$

$$\frac{10 \times 100}{80} = 12.5\text{ grams commercial product for 1 liter of water}$$



C. FIELD SPRAYERS—Occasionally engine driven commercial sprayers are used for large research and demonstration plots. It is equally important that these sprayers be calibrated and operated correctly.

Three methods of calibrating field sprayers are:

Method 1

(1) measure one hectare, acre, or other land unit;
(2) fill the sprayer with clean water only;
(3) spray the area at a predetermined speed and pressure;
(4) refill the sprayer measuring the amount of water needed to do so.

The volume of water consumed provides the calibrated rate of liquid application to be used for calculating the amount of herbicide required.

The same method can be used for a smaller area:

Method 2

(1) place a marker at each end of some convenient length test strip, i.e., 100 meters;
(2) fill the sprayer with clean water;
(3) spray the measured test strip at a predetermined speed and pressure;
(4) refill the sprayer measuring the amount of water needed to do so and solve the following equation:

$$\text{liters/ha} = \frac{10{,}000\ \text{m}^2/\text{ha} \times \text{liters used}}{\text{strip length} \times \text{width of spray swath}}$$

EXAMPLE 2-4

Water consumed: 8 liters
Length of test strip: 100 m
Width of spray swath: 6m

$$\text{liters/ha} = \frac{10{,}000 \times 8}{100 \times 6} = 133.3$$

Another technique for calibrating:

Method 3

(1) fill the sprayer with clean water;
(2) operate the sprayer at a predetermined pressure;
(3) use vessels to collect the water spray discharged from one-third of the nozzles simultaneously during one minute;
(4) have the sprayer move at field speed, then measure the distance travelled in one minute.

The amounts collected for each are measured, then averaged. The average delivery for one nozzle multiplied by the total number of nozzles equals the total discharge.

EXAMPLE 2-5

Total discharge: 8 liters/minute
Width of spray swath: 6m
Distance travelled: 100 m/minute

$$\text{liters per ha} = \frac{8 \times 10{,}000\ \text{m}^2/\text{ha}}{6 \times 100} = 133.3$$

The sprayer has been calibrated at 133.3 liters/ha. The next step requires determining the area to be sprayed and the amount of water needed. Recall that extra water has to be added to fill the hoses and boom, check the nozzles at the beginning of spraying operations, and allow for the small amount of liquid that cannot be pumped out of the sprayer. Usually 30 per cent extra water will be sufficient depending, however, on the number and size of plots and the sprayer type.

EXAMPLE 2-6

Plots (replications) to be sprayed: 3
Plot size: .25 ha

Area = 3 x .25 = .75 ha
= .75 x 30% = .975 ha
or rounding off, 1 ha.

Herbicide enough to spray 1 ha plus 133.3 liters of water is required.

2.13 PRECAUTIONS AND TECHNIQUES

A few, seemingly minor, precautions and techniques can mean the difference between acceptable and non-acceptable data. The following suggestions may help prevent problems and mistakes during application.

(a) Dry formulations should be weighed in the herbicide storage area and put in individual paper envelopes or other containers. Liquid formulations can be measured in the field with a pipette or graduated cylinder; **always use a squeeze bulb for pipetting, never suck with the mouth.** Herbicides at high concentrations can be toxic. They should be transported to the field in sturdy containers only and preferably separately from personnel.

(b) When mixing wettable powders, it is convenient to have two mixing containers: first add some water (about 100 ml) to one of the containers and then add the wettable powder. Stir and mix until a uniform lump-free suspension is obtained. Then add water to reach the total volume desired. The suspension is then thoroughly mixed by pouring carefully back and forth between the two containers. When ready to spray, pour the suspension into the spray tank. It is advisable to mix all formulations in the same manner.

(c) Mixing and spraying a given herbicide should always be carried out in this order: begin with the lowest concentration, then follow with progressively higher concentrations, and then combinations with other herbicides.

(d) Solutions should be applied first, followed by wettable powders, and finally emulsions. This order is based on ease of cleaning different formulations out of spray equipment. The equipment should be thoroughly cleaned between different herbicides. A small amount of detergent or acetone will aid cleaning. Use care with acetone as it is toxic to humans and is rapidly absorbed through the skin.

(e) When mixing emulsifiable concentrates and wettable powders, the wettable powder should be added first followed by the emulsifiable concentrate. This will avoid many compatibility problems between the two formulations.

(f) Drift of spray into adjacent plots should be avoided. Early morning is often a good time to spray. Wind blowing across plots is most troublesome. When the wind is blowing in the direction of the plot length, spraying should be done with the wind at the operator's back. In this way, the effective speed of the wind is reduced by an amount equal to the speed of the sprayer. This will also prevent the herbicide from being blown back on the operator.

(g) When applying foliage active herbicides, attention should be given to the rainfall pattern or forecast. To be effective certain herbicides require a minimum period of time in contact with the plant surface.

(h) Many soil applied herbicides require soil incorporation by mechanical means, irrigation, or rainfall to assure good activity. Weather conditions need to be considered for these processes as well as actual applications.

(i) Clean equipment after spraying and store it in an organized way so it will be ready for use.

(j) A standard application data sheet such as the one shown in Figure 2-12 should be prepared. This form should be filled in before leaving the field each time a research trial is sprayed.

2.14 SOIL PERSISTENCE TRIALS

These tests are conducted to determine the life span of the herbicides in the soil in order to establish the effect, if any, on subsequent crops or persistence and accumulation in the environment. Laboratory and greenhouse tests and field bioassays can be utilized. Laboratory methods involve chemical analysis, gas chromatography, etc., techniques that are much more precise and quantitative than bioassay methods, but which require a higher level of sophistication not always available to the researcher. However, lab methods are inescapably essential for determining environmental residues.

Bioassay, as the name suggests, comprises research based on using an organism to determine biological activity—in this case, using indicator plant species to evaluate the activity of a chemical or treatment. While field bioassays are not as precise as lab methods, they can develop highly practical information. Two approaches can be taken: carry out residue trials as an extension of other herbicide research trials, or establish specific trials for residual activity.

2.14.1 Combined Trials

Plots utilized for either secondary screening or regional trials are carefully conserved and one or more susceptible plant species planted at set time intervals.

HERBICIDE APPLICATION DATA

Title: Annual Ryegrass in Winter Wheat
Established by: B.D. Brewster, R.L. Spinney
Trial location: Hyslop Farm
Trial size: 80 x 200 Plot size: 10 x 20 Replications: 4

Date: October 8, 1976
Day of week: ____

APPLICATION:

Method			Type	Subject
Sprayer: 8004	[X] broadcast	[ ] incorporated	[ ] [ ] [illegible]	[X] [illegible]
PSI: 30	[ ] banded	[ ] ____	[X] [X] [illegible]	[ ] [illegible]
Nozzle: ____	[ ] directed		[ ] [ ] [illegible]	[ ] ____
Gallons: 22 / 220 sq. ft = 34 gal/acre			[ ] [ ] ____	
____ / ____ sq. ft = ____ liters/ha				

Soil:

Type		Moisture		Subject [illegible]
[ ] sand	[ ] silt loam	[ ] very dry	[ ] [illegible]	[illegible] [ ] [illegible] [ ]
[ ] sandy loam	[X] clay loam	[X] dry	[ ] [illegible] wet	[illegible] [ ] [illegible] [ ]
[ ] loam	[ ] clay	[ ] good moisture	[ ] ____	[illegible] [X] ____ [ ]
	[ ] ____	pH 6.4	O.M. 3%	

Site history: None
Other pesticide history: None
Fertilizer history: 300 lbs 16-20-0 Disced into Seedbed
Crop history: Corn in 1975
Type irrigation: Sprinkler

WEATHER:
Air temp: 70 Air humidity: ____ Wind: 2-4 Direction: N.W.
Soil temp: 65 Percent cloud cover: 0

CROP:

Seeding rate	Depth	Row space	Plant space in rows
80 lbs/Acre	2 inches	7 inches	-

Name and variety: Yamhill
Seeding date: October 7, 1976 Stage of growth at treatment: ____
Foliage condition: [ ] wilted [ ] frosted [ ] wet [ ] normal [ ] ____
Harvest date: ____

WEEDS:
Name and stage of growth at time of treatment: ____, ____, ____, ____, ____, ____, ____, ____

NOTES: (method and depth of incorporation, error, etc.) ____

FIGURE 2-12
Application Data Sheet

Soil tillage equipment, if used, should be moved in the direction of the length of the plot rather than across the plot, whenever practical, to minimize movement of treated soil. A new seedbed does not need to be prepared if doing so is not a normal production practice. For example, if beans are normally planted between rows of mature corn with no seedbed preparation, the soil persistance trial should be conducted the same way.

As much old plant material as possible should be removed from the trial site to prevent interferring with planting the indicator species. The seedbed is then prepared and—a very important step—fertilized. If fertilizer is not used to overcome unequal nutrient utilization by the plants in the earlier trials, there will be better growth of the indicator plants in the plots which had the least amount of earlier growth and consequently lowest utilization of soil nutrients. Results of the persistence work will be masked by the effect of varied growth due to nutrient levels.

Residue plots should be kept weed free by hand weeding or by use of a nonresidual contact herbicide.

Bioassays also can be performed in the greenhouse with soil samples taken from treated areas. These samples are placed in pots followed by planting susceptible test species. Effect on germination, growth, and development is recorded.

2.14.2 Specific Residue Trials

Since no former trial-caused fertility difference exists, a specific residue trial tends to be more uniform than a combined trial. A crop usually is not grown; the susceptible (indicator) plant species (one or more) is planted at intervals during the growing season and into the next season if needed. The trial should be kept weed free.

Selection of the test species is very important. If a single species is used, it should be known to have extreme sensitivity to the herbicide. For a second species, the common rotation crop should be used. More than one indicator species should be planted when residual properties of several herbicides are being tested; for instance, consider one or more grass species and one or more broadleaf species. The test species can be either crops or weeds. Some bioassay species for selected herbicides are shown in Table 2-3.

The type of data to collect depends in part on the herbicide and its effect on the test species. Plant counts can be made if the herbicide acts on germinating seeds and emerging seedlings. For the photosynthetic inhibitors (triazines, uracils, ureas, etc.), plant height may be an adequate measurement if the level of activity is fairly high. Plant weight (fresh or dry) may give a more accurate expression of lower residue levels. Certain herbicides can cause obvious symptoms without reducing plant weight. A visual estimation of plant vigor or degree of symptoms may provide the most reliable information. In all cases, the test species, if a crop, can be grown to maturity and its yield recorded.

TABLE 2-3

Bioassay Species Suggested for Selected Herbicide Families

SELECTED HERBICIDE FAMILIES*	BIOASSAY SPECIES
Aliphatic halogenated acids (e.g., *dalapon)*	oats, millet, cucumbers, barley, wheat, rice
Acetamides (e.g., *diphenamid)*	crabgrass, oats, barley, ryegrass, pigweed
Acetanilides (e.g., *alachlor)*	crabgrass, ryegrass
Benzoic acid derivatives	
chloramben	cucumber, oats, foxtail, pigweed
dicamba	beans, sorghum, morning glory
Carbamates	
chlorpropham	cucumbers, oats, ryegrass, crabgrass
karbutilate	sorghum, foxtail
Diphenylethers (e.g., *fluorodiphen)*	cucumber, barnyardgrass, crabgrass
Phenoxy-derivatives (e.g., *2,4-D)*	morning glory, cotton, pigweed, tomatoes, mustard
Substituted ureas (e.g., *diuron)*	cucumbers, ryegrass, barley, oats, millet, sorghum, sugar beets, crabgrass
Thiocarbamates (e.g., *EPTC)*	barnyardgrass, crabgrass, ryegrass, oats, foxtail
Dinitroanalines (e.g., *trifluralin)*	oats, sorghum, crabgrass, rice, ryegrass
Triazines (e.g., *atrazine)*	oats, cucumber, green foxtail, sugar beets, ryegrass, mustard, morning glory
Uracils (e.g., *bromacil)*	oats, barley, rye, millet, sorghum, pigweed
picloram	tomatoes, pigweed, lettuce, cucumber

** The species listed should be considered only as potential bioassay species; investigators need to corroborate for each particular herbicide.*

When the amount of chemical remaining active needs to be estimated, standard curves, based on plotting known concentrations of chemical against reduction of height or weight of the test species, can be used. The measured height or weight reduction caused by the chemical under test is compared to the standard curves of reduction caused by known concentrations to provide the desired information.

Conditions such as soil type, moisture, etc., should be uniform. This more precise type of experiment is conducted in greenhouses, either by using soil from treated field plots, or by simulating field conditions using the same kind of soil.

Generally the results of soil residue trials are expressed as a percentage of the growth of the non-treated plants.

Herbicides which affect root growth present special problems. Under favorable growing conditions, top growth may be normal. When adverse growing conditions occur, the roots may not be able to support normal growth.

Since environmental and soil factors influence herbicide persistence, persistence in the soil at several localities should be tested and each particular set of environmental conditions should be described (type of soil, organic matter, etc.).

Researchers should note that persistence trials can be of quite long duration. However, the effort required decreases with time since plots in which two successive normal growth patterns are obtained can be discontinued.

3 Research Evaluation

- ☐ *Plan logistics for evaluation*
- ☐ *Select methods of evaluation*
- ☐ *Perform evaluation*

Every treatment undergoing evaluation must be compared to current control practices. Factors to be evaluated are: economics, safety to the crop, control of weeds, ease of application, residual activity, compatibility with other pesticides, etc. A single trial will not furnish all the information desired. A research program is broken down into experimental units, each adding information to complete the whole.

An ideal herbicide manifests high selectivity towards the crop, produces a broad spectrum of weed control with sufficient residual activity to afford season-long weed suppression, yet does not carry over into the next growing season. Additionally, it should not present a hazard to the operator nor be corrosive to equipment. Its cost should provide a reasonable margin of monetary gain for the user. Rarely are all of these ideals met; however, they need to be considered when evaluating any new herbicide.

3.1 TIME OF EVALUATION

There are several factors to be considered when choosing the time for visual evaluation:

CROP—evaluations should be made before the crop is large enough to block the weeds from view.

WEEDS—control of established perennial weeds usually requires more time than control of annuals.

HERBICIDE—not all herbicides affect plants at the same speed; some act in a few hours while others may take much longer. If weed mortality is being determined by a single evaluation, enough time must be allowed for even the slowest herbicide to demonstrate its effect. Also, when weeds have not been completely killed, enough time should elapse between evaluations to allow for possible recovery.

ENVIRONMENTAL FACTORS—generally environmental conditions favoring plant growth also favor rapid herbicidal activity.

DISTANCE TO RESEARCH AREA—time required for travel and availability of vehicles may determine the number of evaluations taken and when.

MIXED APPLICATION DATES—it is rare to have all treatments applied at the same time in one trial. Early applications may be ready for evaluation before late applications.

CROP TOXICITY—toxicity symptoms, especially from foliage applications, often are apparent for only a few days following application; evaluations must be carefully timed to observe these symptoms.

These factors usually result in a compromise to allow collecting the maximum amount of information within restrictions imposed by time and resource availability. Often ratings of injury to crops or weeds are taken soon after application, as well as at harvest; control ratings also are taken at 30, 60, or 90 days after application.

Data obtained from weed control experiments can be **qualitative, quantitative,** or both. Qualitative data, though subjective, are a necessary and useful supplement to quantitative data.

In preliminary screening trials, qualitative data usually suffice, but in more advanced trials a combination of qualitative and quantitative data are normally collected.

3.2 QUALITATIVE METHODS OF EVALUATION

Subjective methods, as used in qualitative evaluation, are based on established arbitrary scales. Values ranging along a scale are assigned to each species. The most common method rates percent control of weeds and percent injury to the crop. Zero percent indicates either no control of weeds or no injury to the crop. One hundred percent, applied to weeds, represents complete control; applied to the crop, it indicates complete kill.

Variations of the above methods use the scales 0-10; 0-5; 1-5; and 1-9. These are comparable as shown in Table 3.1.

TABLE 3-1

Qualitative Scales for Rating Degree of Weed Control and Crop Injury

	SCALES			
	Percent	0-10	0-5	1-5
VALUES	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 the 1-5 and 0-5 systems each number represents a level of commercial acceptability. One through three are not acceptable, four is the minimum acceptable level of control, and five is excellent control.

It is difficult to generalize on an acceptable level of control. Acceptability depends on the crop and weeds involved, environmental factors, crop value, and cost and effectiveness of alternative control measures.

Some European researchers use a more complex system in which the scale ranges from one to nine with the value of the scale being reversed between weed control and crop injury. With this system, the scale from one through four is the positive range while six through nine constitutes the negative range.

TABLE 3-2

Suggested European System of Weed Control and Crop Injury Evaluation

Rating Scale	Effect on Weeds	Effect on Crop
1	Complete kill	No effect
2	Very good	Very light symptoms
3	Good	Light symptoms
4	Sufficient in practice	Symptoms not reflected in yield
5	Medium	Medium
6	Fair	Fairly heavy damage
7	Poor	Heavy damage
8	Very poor	Very heavy damage
9	No effect	Complete kill

Other methods compare percent cover and vigor by species. Again the control plot is used as reference. Percent cover and vigor allow evaluation of stand (cover) and growth (vigor).

Changes in weed population and composition from one plot to another frustrate even the most experienced researcher. A natural shift in density of a given species, or a change from one part of the trial to another part, causes variation. Variation also occurs when a plot treatment controls the dominant species sufficiently to allow another species to grow. If the second species is not present in the control plots, or in plots where the treatment did not control the dominant species, there is no reliable way to assess the amount of control in treated plots. The researcher then has the option of using a "present-absent" system or guessing at a control level based on population in nearby plots.

On the sample data evaluation sheet (Figure 3.1) observe that each primary weed species is evaluated independently and that specific notes are to be taken long-hand when needed. Weeds can be grouped into the broad categories of grasses, broadleafs, and sedges satisfactorily for only the secondary weed population and then only after a list of these weeds has been recorded.

TITLE Annual Weed Control in Corn

PLOT NO	Corn Injury	Barnyardgrass Control	Foxtail Control	Pigweed Control	Purslane Control
102	0	80	90	100	100
103	0	50	50	90	80
104	0	100	100	100	100
105	0	80	50	70	50
106	0	90	80	80	80
107	0	20	30	90	90
108	10	100	90	50	80
109	0	50	50	40	80
110	0	90	90	80	70
111	0	80	70	50	30
112	40	100	100	80	80
113	0	90	80	90	90
114	20	70	70	80	90
115	0	40	50	60	80
116	0	80	80	70	80
117	0	90	80	30	20
118	0	90	90	70	80
119	0	0	0	0	0
120	0	50	50	100	100

PLOT NO	Corn Injury	Barnyardgrass Control	Foxtail Control	Pigweed Control	Purslane Control
202	30	90	90	80	70
203	0	100	90	50	80
204	0	50	50	90	90
205	0	100	100	100	100
206	10	50	50	40	80
207	0	90	80	30	20
208	0	50	50	100	100
209	0	60	90	50	80
210	0	70	100	90	80
211	0	100	90	80	50
212	50	100	100	90	80
213	0	0	0	0	0
214	0	20	30	80	90
215	0	50	80	100	100
216	0	90	50	80	80
217	0	100	100	30	20
218	0	50	60	100	100
219	0	80	80	50	90
220	0	70	90	80	80

Date Evaluated July 8 1976

Evaluated by Fraser

Remarks - Barnyard grass population was very heavy throughout trial

FIGURE 3-1
Sample Data Evaluation Sheet

A well-tested, practical technique for making visual evaluations follows:

STEP 1: walk over the entire test to get an idea of overall results and any change in crop growth or weed population in different parts of the trial.

STEP 2: observe the control plots closely.

STEP 3: perform evaluation without knowledge of the treatments in each plot, except the control plot; to do this evaluate the trial moving from back to front, so that plot markers cannot be read.

STEP 4: compare results in each replication and double check to make sure 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: it is preferable that two people evaluate each trial independently so results can be pooled, particularly with respect to subjective data.

Universal acceptance of one system would be desirable, but will probably not happen. Therefore, each researcher should choose the system which best fits his particular program. All of the methods mentioned have inherent weaknesses, but can be useful as an unbiased evaluation, providing an excellent contribution to understanding of the treatments. Regardless of the scale used, consistency and objectivity should be stressed. The researcher has the responsibility to use his best judgment in recording what actually happened, rather than just describing the results with no regard for non-treatment effects on the plots.

NOTE: In the event of using more than one system it is important that a careful explanation be included with each report.

Qualitative data are *usually* not subjected to statistical analysis. However, for special purposes, it is acceptable to do so. When the system includes a zero value, an appropriate transformation (log, arc sin, etc.), is usually applied to the data prior to analysis.

3.3 QUANTITATIVE EVALUATIONS

Quantitative measurements provide data that are not influenced by inconsistencies or the evaluator's bias. They can also develop subtle differences which the evaluator may miss. However, quantitative evaluations may not overcome problems of variation due to factors other than the treatments (i.e., rodents, irrigation patterns, equipment, etc.).

Collecting quantitative data consumes time and money. Collection should occur only with a planned objective in mind and with trials designed to provide maximum needed information. Special attention should be given to:

— **planning** (experimental design, plot size, number of treatments, number of replications, and number of experiments);

— **site selection** (represents area, travel time, adequate control);

— **cultural practices** (uniformity—often more important than level of inputs, pest control).

There are several classes of quantitative data.

3.3.1 Weed Counts

Actual density of weeds can be useful information when interpreting either visual evaluations or yield data. However, weed counts fail to reflect the practical effect of a few large weeds compared with a large number of small weeds.

Weed counts can be made by placing a quadrate at random locations in plots and counting plants within the quadrate. Size of the quadrate and number of

counts made within each plot should depend on plot size and weed density. Quadrates should not be placed completely at random when there are areas within the plots which have been influenced by factors other than the treatment, i.e., rodents, irrigation, equipment, etc.

FIGURE 3-2

Using a Quadrate to Count Weeds

3.3.2 Plant Weight

Research with perennial crops, forage crops (and in other experiments where the crop cannot be carried to maturity) frequently includes harvesting all or part of the plots and recording fresh weight. The species

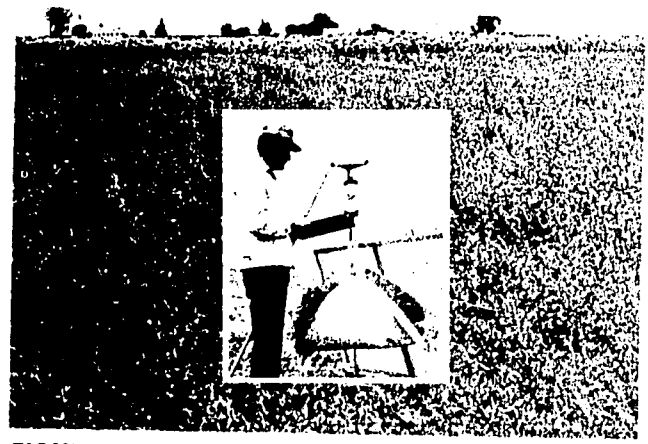


FIGURE 3-3

Weighing Plants in the Field

are then separated by hand and weight of individual species determined.

Often, each sample's dry weight is determined to eliminate errors caused by unequal water loss between harvest and weighing fresh samples. Dry weights alone do not yield definitive data due to large water content variations of different species.

3.3.3. Plant Height

With many annual crops, forage crops, young woody perennials, and trees, plant height provides a useful measurement of herbicide toxicity and weed competition. Plant height—as well as plant weight and weed count—data are often collected to supplement final yield data and may or may not correspond to final yield. Measurable differences in physical characteristics of a plant often have no effect on yield.

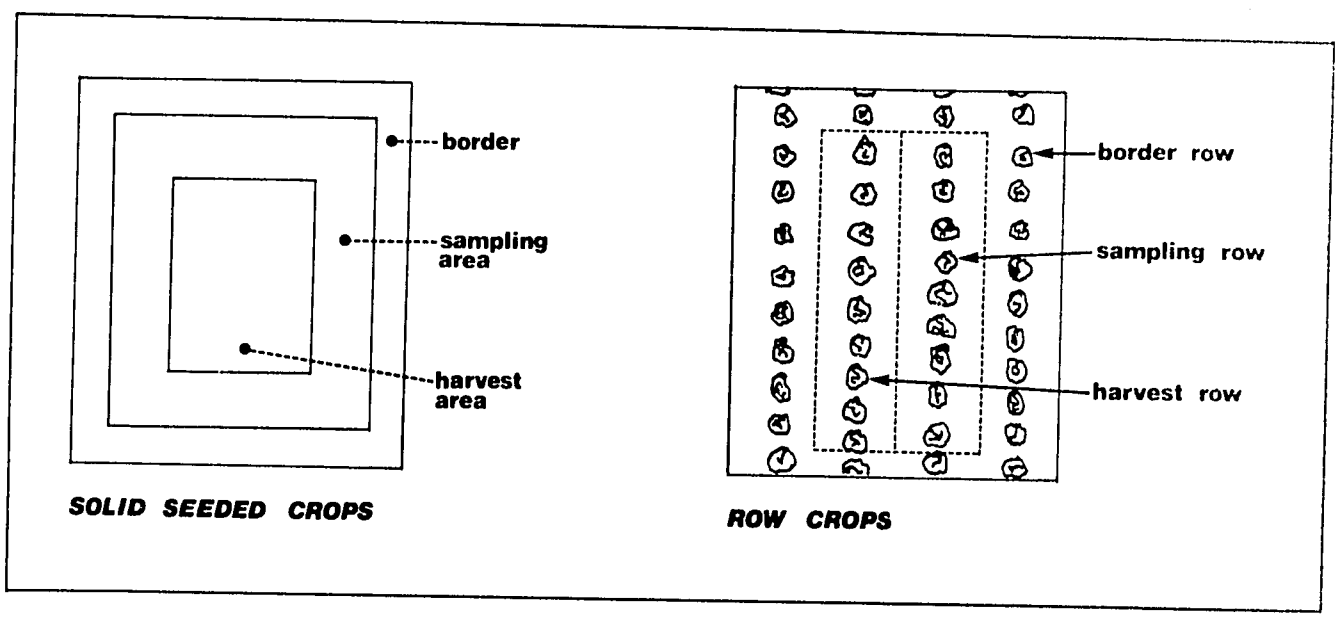


DIAGRAM 3-1

Sampling Areas for Solid Seeded and Row Crops

3.3.4 Sampling Area

One or more of the above measurements can be collected from yield plots if yield data are needed. An effort should be made to minimize disturbance of plants in the area to be harvested. When the crop is solid seeded, such as wheat or alfalfa, measurements can be made in a separate area of the plot leaving another area undisturbed until harvest time.

Corn, beans, and other row crops can be measured relatively easily without disturbing other plants. Separate areas should be used if measurements involve cutting or pulling plants. Harvesting equipment, if used, must be considered when determining the size of the various areas. Hand harvesting allows much more flexibility and smaller sampling areas.

3.3.5 Crop Yield

The final—and most important—type of quantitative data is crop yield. Recommendations for cropland use of herbicides must be supported by good yield data. The majority of the preceding quantitative evaluations discussion applies equally to the collection of yield data. However, there are additional factors which deserve special attention.

The number of treatments should be minimized to allow harvest during a reasonably short time period, preferably one day. Experiments should be harvested by replication to reduce differences in results if harvest is interrupted.

Special problems arise for crops such as tomatoes and cucumbers that ripen over a period of weeks and which must be harvested every few days. These conditions present high potential for error. In such cases, a period of time may be established for harvesting all treatments and no data taken thereafter.

Another problem develops when herbicide treatments, or weed competition, delays or hastens 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 between different experiments.

Adjustments in weights can be made using the following formula:

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

EXAMPLE 3-1

Recorded sample weight: 450

Measured moisture content: 16 percent

Designated moisture content: 14 percent

$$450 \times \frac{100\text{-}16}{100\text{-}14} = 440 \text{ at 14 percent}$$

Even with the best planning and greatest effort, many experiments are rendered valueless by uncontrolled factors causing excess variation in results. Researchers must recognize, as early as possible, when to abandon a trial. Though it is not easy to discard the results of considerable effort, it is even less desirable to continue work that will produce useless or misleading data.

Visual evaluations may be more useful than quantitative evaluations when faced with non-uniformity. A biologist is often able to make allowances for variation due to non-treatment factors such as insects, disease, rodents, and weed or crop population.

Statistical and sampling techniques may be available to avoid the loss of all data. For example, yield may be taken on a per plant basis rather than a per plot basis if plants have been damaged in some plots. Treatments or blocks can be discarded without seriously affecting the analysis. It is usually helpful to consult a statistician when coping with such problems.

4 Data Analysis and Statistics

- ☐ ***Design experiment to facilitate analysis***
- ☐ ***Carry out statistical analysis***
- ☐ ***Utilize analysis in reports***

After plots have been evaluated and harvested, the resulting data should be statistically analyzed to provide an objective method for assessing whether experimental treatments or uncontrolled variation and chance caused differences. All the previous work and planning supporting execution of the experiments can be wasted if harvest or evaluation data are handled carelessly or errors are committed in analysis.

4.1 PLANNING FOR ANALYSIS

Researchers should apply equal care to each step in the experiment design and data analysis process:

— definition of research objectives and the experimental design;

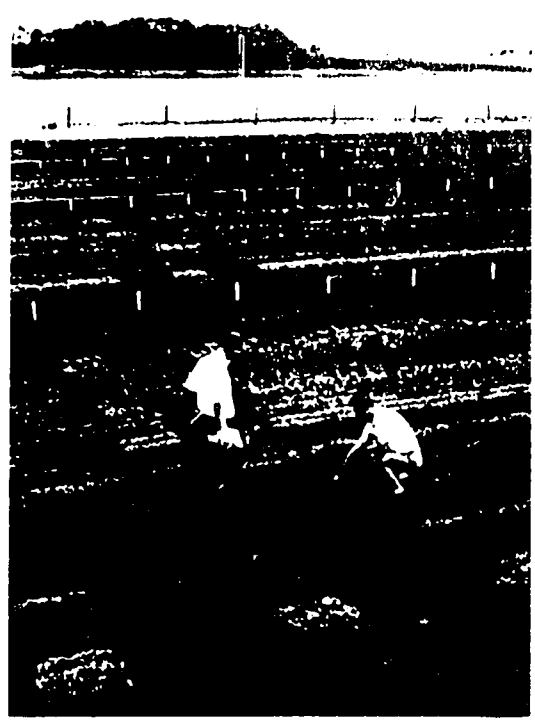
— data recording and preparation;

— statistical analysis;

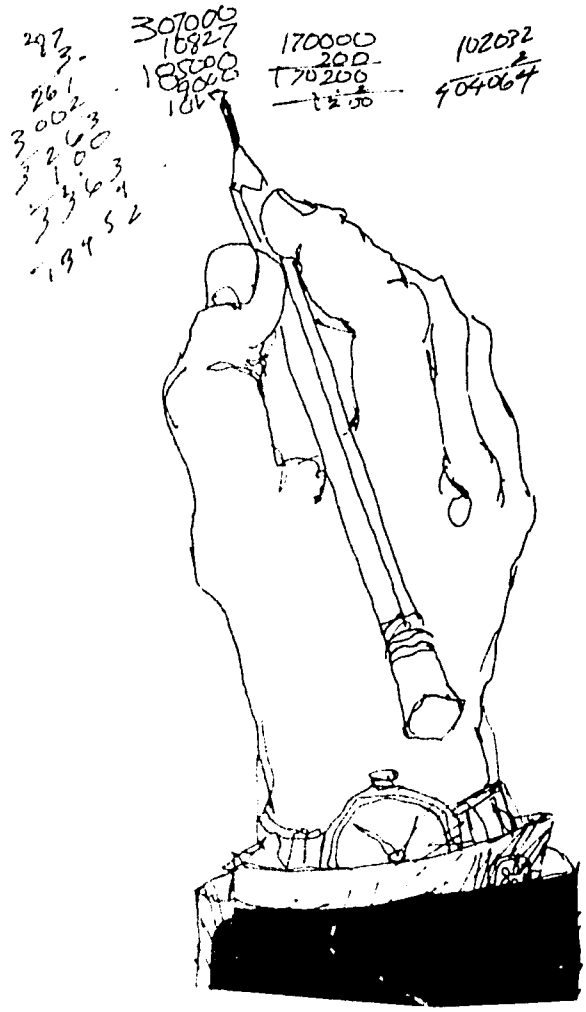
— interpretation and utilization of the results.

Planning for statistical analysis begins at the time the experimental design is determined, long before planting. Researchers should clearly define the hypotheses under test and then adopt an appropriate design for testing them. If the appropriate experimental design or statistical procedure is unclear, consult a trained statistician during this initial planning stage. Serious flaws in experimental design (e.g., failure to use randomization, or failure to replicate treatments) will invalidate any statistical analysis of the results.

Every effort should be made to record initial data accurately. Recording directly on prepared forms facilitates comparing replications. Questionable numbers are obvious immediately; the accuracy of preceding evaluation, harvest, or weighing operations can be checked on the scene. Revisiting the plot at this point can often correct an error.



Similar care should be exercised in adjusting raw data to a constant moisture content, or converting



small plot yields to more meaningful area basis (e.g., per acre or hectare). Arithmetic should *always* be double checked.

4.2 STATISTICAL ANALYSIS

This section does not provide a "cookbook" list of specific formulas and statistical procedures. Ideally, a field researcher should be familiar with basic statistical procedures for detecting differences among treatment results, and capable of consulting statistics references when needing special procedures for handling new problems or to review computational formulas.

There is no substitute for personal knowledge of fundamental statistical methodology. Understanding the theory, limitations, and potentials of statistical procedures makes the field researcher a more effective scientist. Recognizing the importance of minimizing experimental error to obtain significant differences reinforces the researcher's incentive to select sites, lay out blocks, and implement treatments to achieve maximum uniformity for all factors except the treatment variables being studied. Comprehending statistical procedures enables the researcher to salvage considerable data from "lost" plots, or when errors are made. Finally, knowing statistical analysis requirements enables the researcher to design experiments achieving particular objectives with minimum time and money expenditure.

Once the experimental design has been established, evaluations and harvest completed, and data prepared, actual statistical analyses can be carried out by hand or computer. The researcher should ensure that all tests and analyses relating to detailed questions of interest are performed. A conventional analysis of variance over all treatments is often just a first step; further tests are needed to make more detailed generalizations.

Statistical tests, by themselves, are only a tool to determine if significant differences exist among treatments. The researcher carries responsibility as a scientist to attempt to explain why certain results were, or were not, significantly different. Often special knowledge of an experiment can shed light on these questions. Results should be compared with other similar research and an effort made to resolve differences.

Finally, statistical analysis results should be utilized in making recommendations or performing additional analysis. If treatment "A" shows no significant performing superiority to treatment "B" at the established confidence level, and this result is consistent with previous work, then the two treatments must be regarded as equally effective until further evidence is available. For an economic analysis of the results, equal yields should be assigned to nonsignificantly different treatments. Substantial but nonsignificant differences in treatments can and should indicate promising directions for future research.

4.3 ECONOMIC ANALYSIS

Since farmers worldwide generally respond to economic incentives, many reseaarch and extension communications that describe weed control techniques should also present economic analyses—in terms of direct costs and benefits related to weed control.

Both agronomic and economic factors continually evolve with time thereby creating uncertainties. These uncertainties should be incorporated into the economic analyses; the degree of, and procedure for handling, economic uncertainty should be explained with the same vigor used to discuss technical uncertainty.

Economic analysis of agronomic experiments can be most effectively performed in cooperation with an agricultural economist. The economists' input should be solicited and considered before, rather than after, establishing field experiments. The various costs and benefits associated with weed control need to be defined. Considering a particular crop, or an entire farming enterprise, or the overall social welfare will determine the nature of technical economic measurements required in a research trial.

5 Recording and Reporting Results

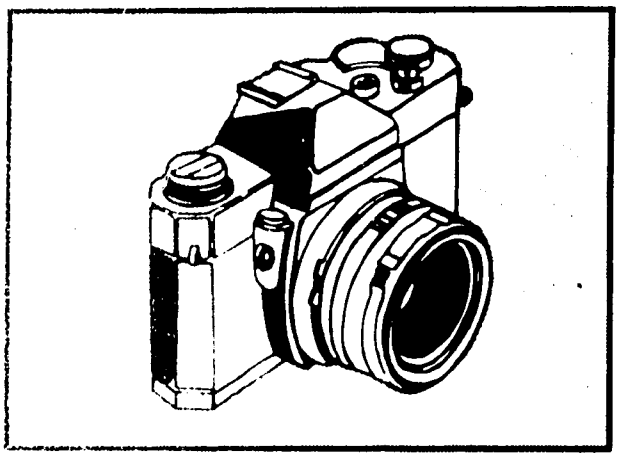
- ☐ ***Carefully note and record full information***
- ☐ ***Include sufficient information in reports***

Many useful experiments are conducted each year and never reported, while many others that are reported lack important information. Failure to record and report results and supporting information essentially cancels most of the effort and resources required to conduct an experiment. This situation holds true for both research organization work and for large farm or plantation research that has a goal of immediate production use. The latter case may be a report intended for limited usage, but it should still contain sufficient detail to enable future close duplication of the research.

For reporting a series of similar trials, some of the repetitive information possibly may be grouped. There are the several classic categories of information to include in a report.

5.1 BACKGROUND INFORMATION

Background information should consist of the definition of the problem's nature and extent with a concise discussion of the problem including a reference to the activities or decisions that prompted establishing the experiments.



5.2 MATERIALS AND METHODS

Equipment, materials used, cultural practices, experiment location, people involved, methods employed, and experimental design should be set forth briefly and in such a way that allows a reader to duplicate the work under similar conditions.

5.3 APPLICATION DATA

All the information recorded when treatments are applied should be included in this section. Soil type, species and cultivars present, soil and air temperature, weather conditions, dates, stage of growth of crop and weeds, herbicide treatments, spray additives and type and volume of carrier are examples of information to include.

5.4 RESULTS

Data are usually presented in tabular form. The heading of the table should be brief, yet descriptive enough not to force the reader to refer back to the text. The title, location, and date of the experiment should be included. Headings used for data columns need to be readily understood, perhaps requiring an explanatory footnote.

Reports may be read and used by people unfamiliar with the research area. Hence, the report has to pro-

Weed Control in Pinto Beans
Malheur Experiment Station, Ontario, Malheur County, Oregon, 1975

						Visual Evaluations[a] - % Weed Control															
	lbs	% Crop Injury				Barnyardgrass				Pigweed				Purslane				Lambsquarters			
Treatment	a.i./A	R1	R2	R3	Avg	R1	R2	R3	Avg	R1	R2	R3	Avg	R1	R2	R3	Avg	R1	R2	R3	Avg
ethalfluralin	1.0 ppi	10	5	5	7	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
fluchloralin	.75 ppi																				
+ bentazon	+ 1 post	15	20	25	20	100	98	98	98	100	100	100	100	100	100	100	100	100	100	100	100
penoxalin	.75 ppi	0	20	10	10	98	100	99	99	99	100	100	99	99	100	100	99	99	100	100	99
penoxalin	1.0 ppi	50	40	30	40	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
penoxalin	1.5 ppi	65	70	70	68	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
HOE 23408	2.0 post	0	10	10	7	100	100	100	100	0	0	0	0	0	0	0	0	0	0	0	0
HOE 23408	4.0 post	30	20	20	23	100	100	100	100	30	40	40	38	30	40	40	38	30	50	40	40
desmedipham	1.0 post	85	60	70	72	20	50	40	37	100	100	100	100	100	100	98	99	100	100	100	100
SN 36575	1.0 post	0	0	0	0	0	0	0	0	95	95	90	93	98	95	95	96	98	98	95	96
SN 38622	1.0 post	5	5	5	5	90	90	90	90	98	95	98	97	98	98	98	98	98	95	98	96
Check	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

[a]Evaluation Scale: 0 = no kill, 100 = complete kill Evaluated July 28, 1975

penoxalin at 1.5 lb/A rate had reduced stand, caused growth reduction and the chlorosis of lower leaves.
ethalfluralin seems to have good cantaloupe tolerance emerging from seed.
penoxalin at 1.5 lb/A has controlled mallow.

General Information
- Crop - Dry beans (Pinto)
- Plot size - 5 rows x 35'
- Soil type - silt loam
- Soil organic matter - 1.3%
- Irrigation - furrow

Application Data		
Date:	June 30, 1975	July 10, 1975
Conditions:	Preplant incorporated	Postemergence
Method of Application:	Broadcast	Broadcast
Carrier volume	40 gpa	40 gpa
Nozzle size	8003 TeeJet	8003 TeeJet
Pressure	35 psi	35 psi
Stage of Growth:		
Dry beans	Preemergence	Emerging; first trifoliate
Barnyardgrass		1-4 leaf
Redroot pigweed		2-3 leaf
Purslane		2-3 leaf
Lambsquarters		2-3 leaf

FIGURE 5-1

Presenting Results Data—Tabular Format

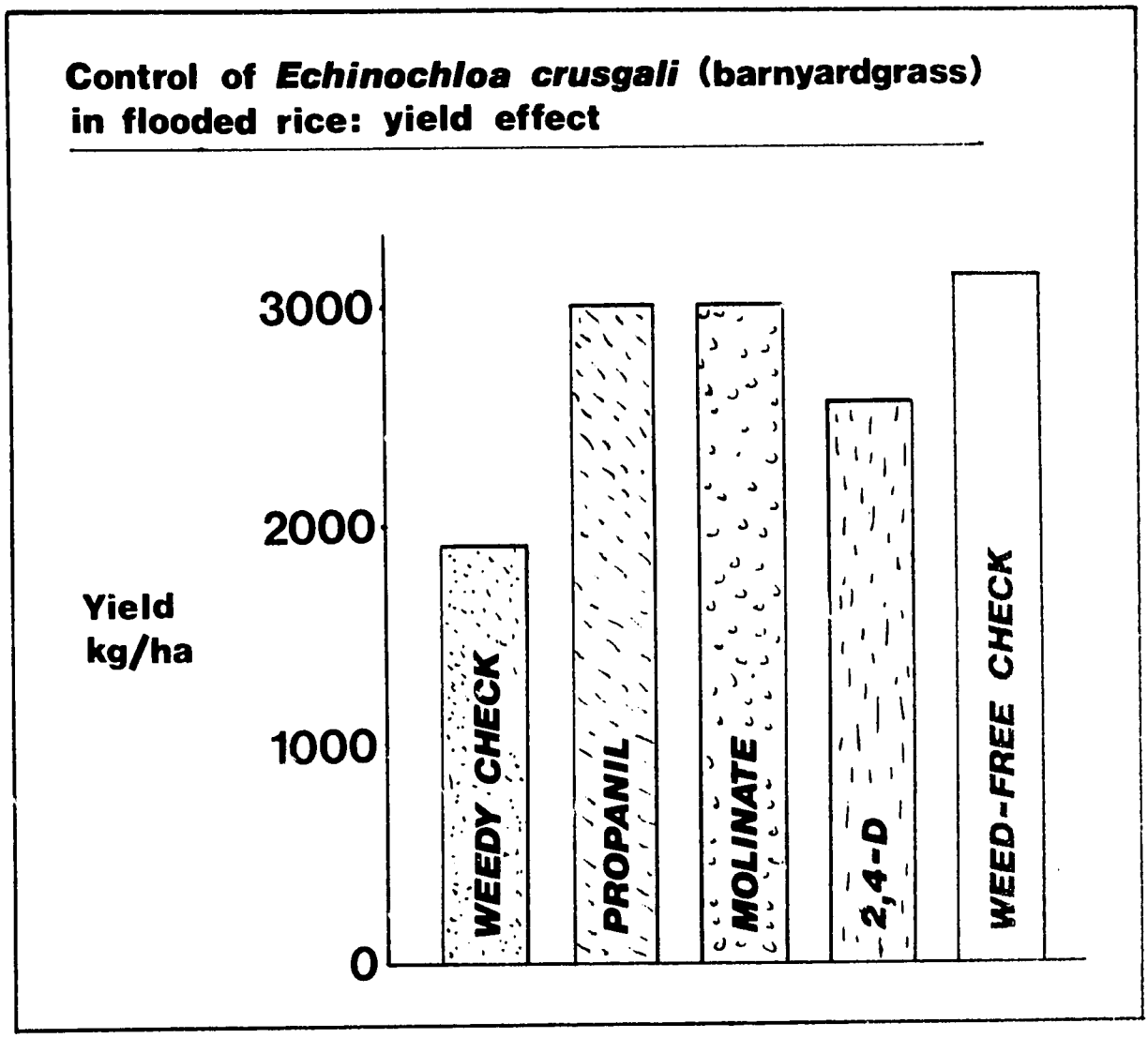


FIGURE 5-2

Presenting Results Data—Graph Format

vide enough information to help them interpret the data. Many times data alone will present a confusing picture; written discussion of the results, and the factors influencing them, may be more useful than the numbers. The person on the scene and most familiar with the experiment usually can best provide interpretations. Figures presenting results in graph form may provide a desirable alternative to the usual tables.

6 Safety

- ☐ ***Use safe procedures to store, handle and apply herbicides***
- ☐ ***Know and be able to employ first aid measures***
- ☐ ***Follow approved disposal techniques***

6.1 HERBICIDES AND SAFETY

Herbicides are chemicals and must be handled with caution. Although most are relatively non-toxic compared to other pesticides, some, such as the substituted phenols, are highly toxic.

Toxicity can be acute or chronic; attention often focuses only on the acute form. Less information is available on chronic toxicity; however both forms should be kept in mind. For instance, researchers are more likely to suffer chronic toxicity from handling herbicides than acute toxicity from swallowing them.

Herbicides can be hazardous when ingested, absorbed through the skin, splashed into the eyes, or inhaled as spray or dust. **The general rule: for ingestion of noncaustic materials, induce vomiting; for caustic materials, vomiting should not be induced.** In any event, material should not be allowed to get into the trachea and lungs (respiratory system). For skin contamination, the exposed area should be thoroughly rinsed with water followed by an extensive washing with soapy water and then a second thorough rinse. Eye contamination requires thorough multiple washings with clean water.

A person with the first suspicion of complications should be taken to a hospital for surveillance and medical care.

In some regions there are reference centers on poisoning that can be contacted for information, or in case of emergency. Researchers working in areas where this service is not available should keep a list of first aid measures handy for the different types of herbicide intoxication.

Labels of commercially available herbicides should contain indications as to toxicity, and some contain first aid measures. This information is usually not provided with experimental herbicides. Consequently the latter should be handled as dangerous materials.

ALWAYS READ AND HEED THE HERBICIDE LABEL

Toxicity is most commonly expressed in the form of median lethal dose (LD_{50}). The LD_{50} alone is not sufficient since it only indicates the dose which kills 50% of a given population (i.e., that dose at which 50% of a given population of test animals dies). It says nothing of the dosage range causing death or of the non-lethal effects.

TABLE 6-1

Variability in Lethal Dose

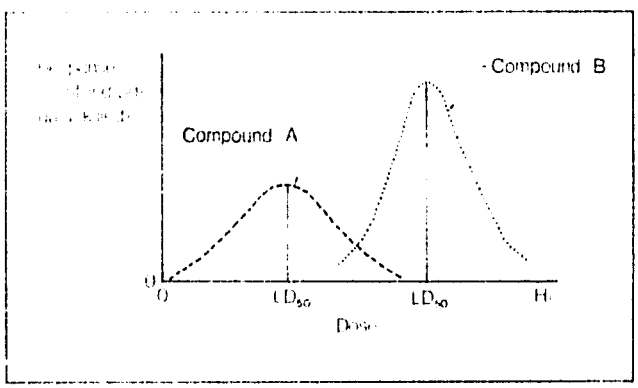
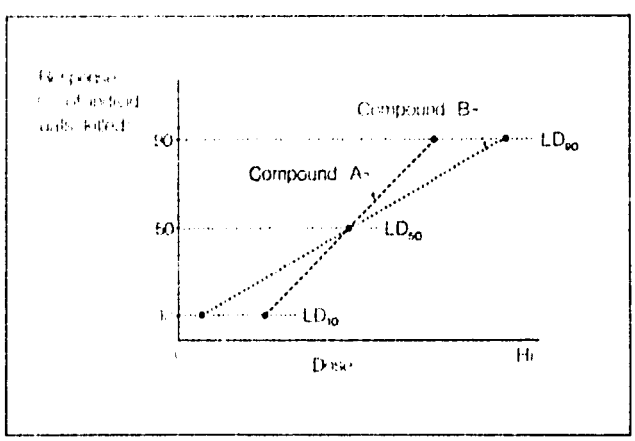


TABLE 6-2

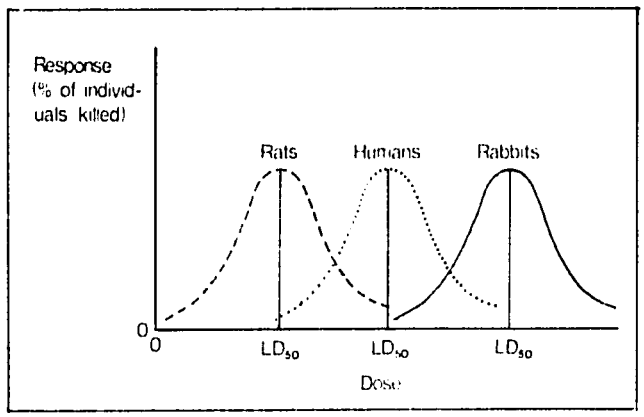
Different Compounds, Same LD_{50}, Different Dose-Response Curves



Note: these data are based on laboratory studies. Test animals, such as rats or dogs, tested under artificial conditions, may respond differently than humans. These data should be considered principally from a comparative point of view. Based on this information, side effects on animals or the environment which develop over a long period of time are very difficult to predict.

TABLE 6-3

Hypothetical LD_{50} Response of Different Animal Species to the Same Compound



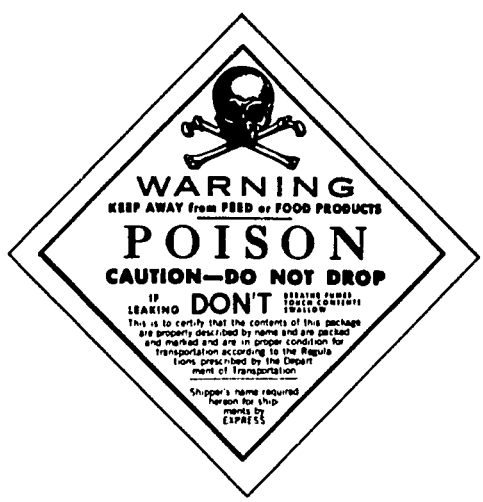
There may exist many serious harmful effects short of death.

Dosage-mortality relationships such as LD_{50} help to clarify varying individual or group reactions to a poison. Thus they are useful in comparing pesticides and susceptibilities.

Personnel likely to be in contact with herbicides should have a thorough understanding of each compound's toxicity, initial toxicity or allergy symptoms, and first aid measures.

All crops which have been treated with non-registered herbicides should be disposed of in an appropriate manner. They should **never** be used for food or feed. All **reasonable** attempts should be made to reduce the risks involved in herbicide usage. Herbicides should be used, not abused. Improper usage may result in damage or harm to humans, animals, the crop, or vegetation in general.

MOST TOXICITY PROBLEMS ARISE WHEN HANDLING CONCENTRATED MATERIAL.



6.2 HERBICIDE STORAGE

Herbicides should be stored in a specific room, shed, or area having a lockable entry with key(s) assigned only to authorized individuals.

The storage area should be maintained above freezing temperature and protected from excess heat; use a fan if necessary. Adequate ventilation is also essential and a washable floor (preferably concrete) desirable. Sunlight entering the area should be kept off glass containers to prevent light-caused degradation.

Store herbicides in an orderly system; they should be dated on receipt and discarded after two years if intended for research work (one year in the tropics). A periodic inventory helps to maintain fresh, adequate supplies of herbicides.

It is imperative that there be no smoking around chemicals. Most solvents used to dissolve herbicides are flammable so the use of matches, flame, or cigarettes may cause a serious accident. Storage and mixing areas should be equipped with a chemical fire extinguisher.

FIGURE 6-1

Disposing of Pesticide Containers

Herbicide supplies should be inventoried periodically and old, outdated materials discarded. Perhaps the best method is application on a crop at the recommended rate. Attempt to precisely calculate the amount of new chemicals required for the year and do not request excess; avoid accumulating materials that will deteriorate with age. Farmers also should be advised not to buy more chemical than will be used during the period that it is factory-guaranteed to be active.

6.3 DISPOSAL

Herbicide containers (drums, cans, bottles, etc.), though appearing to be empty, may still hold traces of herbicide. All such containers should be rinsed thoroughly, perforated or broken, and disposed of by burying. Never reuse former herbicide containers to carry water, etc. Certain materials are not decomposed by burning; therefore, humans and animals should not be exposed to the smoke from burning containers.

Waste water from the preparation area needs to be carefully controlled. It should not be allowed to run into an area where it may be used by humans or animals; also, it should be kept away from crop irrigation systems.

Do not dump excess chemicals after spraying, except in a specific disposal pit or other area that will not result in land, crop, or other environmental contamination.

6.4 APPLICATION

Certain safety steps should be observed when spraying herbicides.

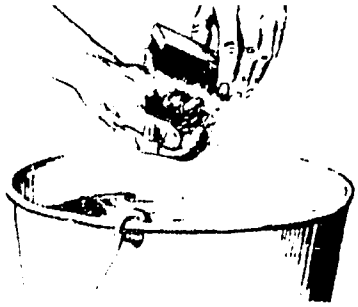
6.4.1 Wind

Avoid spray applications when blowing wind will cause spray to drift onto nearby persons, crops, or test plots. Spray can be applied during moderately breezy conditions provided application moves in the direction of the wind; spray will then be blown away from, not onto, the operator.

When wind is a problem, reduce drift by using nozzles that emit a coarse spray. Also operate a sprayer at the lowest possible pressure consistent with spraying needs and label recommendations.

6.4.2 Protective Gear

For his own safety, a person applying pesticides (an operator) should understand the potential hazards to himself and others and should be properly motivated



to take necessary precautions. An operator should both change clothing (and have it washed) and bathe thoroughly with soap and water after each day's spraying operations. Protective clothing should be worn (depending on the toxicity of the herbicide being applied) including a long-sleeved shirt or coat, hat, rubber gloves, respirator, and eye protector. In hot humid climates such clothing will not be comfortable, but should be used when indicated.

FIGURE 6-2

Wearing Protective Gear During Application

COMMON SENSE AND CAUTION WILL PREVENT MOST TOXICITY PROBLEMS

Common sense and an accurate, cautious approach to research will prevent most problems. An operator must **not** drink, eat, or smoke while spraying or handling herbicides.

7 Measures Equivalents Conversions and Rates

7.1 THE METRIC SYSTEM

The fundamental unit of the metric system is the meter (unit of length) from which the gram (unit of mass) and the liter (volume) are derived; all other units are either the decimal subdivisions or multiples thereof. The three basic units are related, so that for all practical purposes one kilogram of water equals one liter or one cubic decimeter.

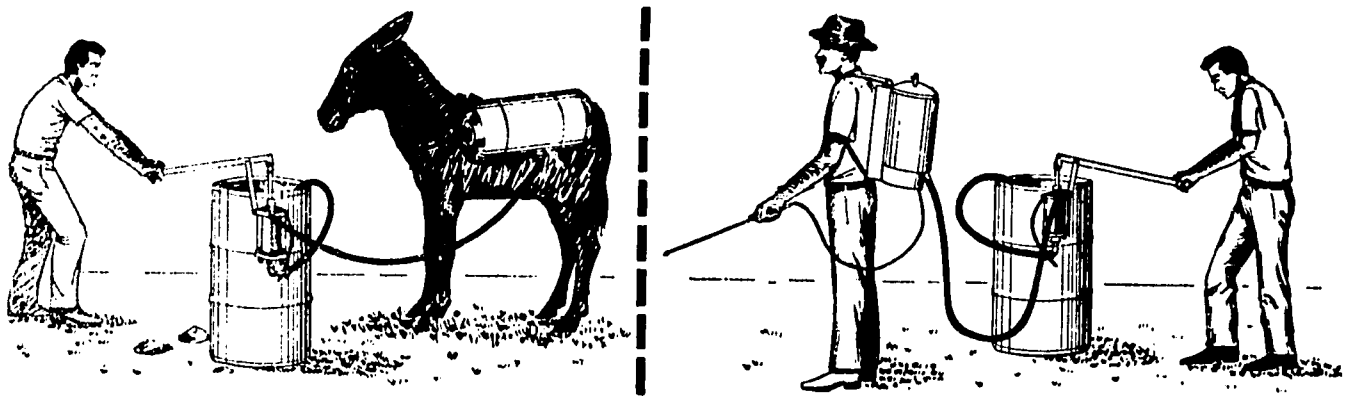
Many metric terms are formed by combining six numerical prefixes with the base units.

Ten of one metric measure equals one of the next larger measures, e.g., 10 millimeters equal one centimeter. The square and cubic units are the squares and cubes of the linear units. The ordinary unit for land area is the hectare.

CHART 7-1

Some prefixes and Relationships in the Metric System

prefix	meaning	decimal	fraction	power of 10
kilo-	one thousand	1000.	$\frac{1000}{1}$	10^3
hecto-	one hundred	100.	$\frac{100}{1}$	10^2
deka-	ten	10.	$\frac{10}{1}$	10^1
(none)	one	1.	----	--
deci-	one tenth	.1	$\frac{1}{10}$	10^{-1}
centi-	one hundredth	.01	$\frac{1}{100}$	10^{-2}
milli-	one thousandth	.001	$\frac{1}{1000}$	10^{-3}



The finer subdivisions of measurement, MICRO (10^{-6}), NANO (10^{-9}), and PICO (10^{-12}) are additional prefixes sometimes usefully employed, especially with units of mass (gram) and capacity (liter).

The abbreviations for metric units are formed by combining one or two letters from the prefix with m (meter), g (gram) or l (liter):

TABLE 7-1

Some Abbreviations in the Metric System

millimeter - mm	milligram - mg	millileter - ml
centimeter - cm	centigram - cg	centiliter - cl
decimeter - dm	decigram - dg	deciliter - dl
meter - m	gram - g	liter - l
dekameter - dkm	dekagram - dkg	dekaliter - dkl
hectometer - hm	hectogram - hg	hectoliter - hl
kilometer - km	kilogram - kg	kiloliter - kl
hectare - ha		

7.2 U.S. MEASURES

The terms used for U.S. (and some Imperial measurements) with abbreviations, are:

LINEAR

--inches, feet (ft), yards (yd), rods, miles (mi);

WEIGHT

--ounces (oz), pounds (lb), tons (T);

VOLUME

--fluid ounces (fl oz), pints (pt), quarts (qt), gallons (gal);

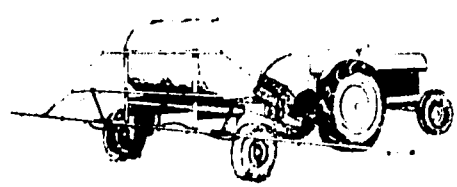
AREA, CUBIC

--acre (a), or linear terms preceded by sq (for square) or cu (for cubic).

7.3 EQUIVALENTS

7.3.1 LINEAR

1 centimeter (cm)	= .3937 inches
1 meter (m)	= 100 cm
	= 39.37 inches
	= 3.28 feet (ft)
	= 1.094 yeards (yd)
1 inch	= 2.54 cm
1 foot	= 30.48 cm
	= 12 inches
	= .333 yd
1 yard	= 36 inches
	= 3 ft
	= 91.44 cm
	= .914 m
1 rod	= 5.029 m
	= 5.50 yd
	= 16.5 ft
1 kilometer (km)	= 1000 m
	= .621 miles (mi)
1 mile (m)	= 1.609 km
	= 1,760 yd
	= 5,280 ft
	= 329 rods

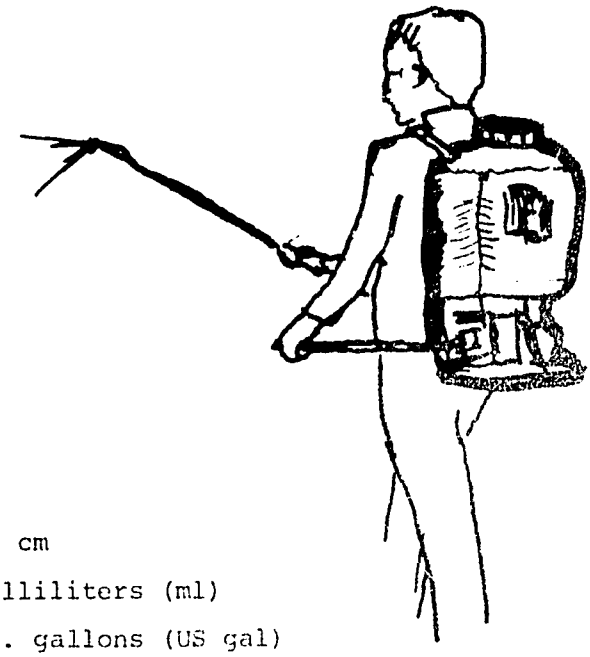


7.3.2 AREA

1 square centimeter (sq cm)	= 0.155 square inches (sq inches)
1 square meter (sq m)	= 10,000 sq cm
	= 10.764 square feet (sq ft)
	= 1.196 square yards (sq yd)
1 sq inch	= 6.451 sq cm
1 sq ft	= 929.01 sq cm
1 sq yd	= 8361.3 sq cm
	= 0.836 sq m
	= 9.00 sq ft
	= 1,296 sq inches
1 hectare (ha	= 2.471 acres (a)
	= 10,000 sq m
	= 107,640 sq ft
1 acre(a)	= 0.405 ha
	= 4,046.8 sq m
	= 4,840 sq yd
	= 43,560 sq ft
	= 160 square rods (sq rods)
1 sq mi	= 259.2 ha
	= 640 a

7.3.3 VOLUME

1 cubic centi-	= 0.0353 ounces (oz)
meter (cu cm)	= 0.0353 ounces (oz)
1 cubic meter (cu m)	= 1.308 cubic yards (cu yd)
	= 35.315 cubic feet (cu ft)
1 cu inch	= 16.3871 cu cm
1 cu ft	= 0.0283 cu m
	= 1,728 cu inch
	= 0.037 cu yd
1 cu yd	= 0.765 cu m
	= 27 cu ft
	= 46,656 cu inch



7.3.4 LIQUID

1 liter (l)	= 1,000 cu cm
	= 1,000 milliliters (ml)
	= .264 U.S. gallons (US gal)
	= .22 Imperial gallons (Imp gal)
	= 61.0224 cu inch
1 US gal	= 213 cu inch
	= 4 US quarts
	= 3.785 l
	= .8327 Imp gal
1 Imp gal	= 277.42 cu inch
	= 4 Imperial quarts (Imp qt)
	= 4.545 l
	= 1.2 US gal

7.3.5 MASS

1 gram (g)	= 0.0353 ounces (oz)
	= 1,000 milligrams (mg)
	= .001 kilogram (kg)
1 kg	= 35.274 oz
	= 2.2046 pounds (lb)
1 oz	= 28.349 g
1 lb	= 453.59 g
	= 16 oz
	= .4535 kg
1 ton (T)	= 2,000 lb
	= 906.8 kg

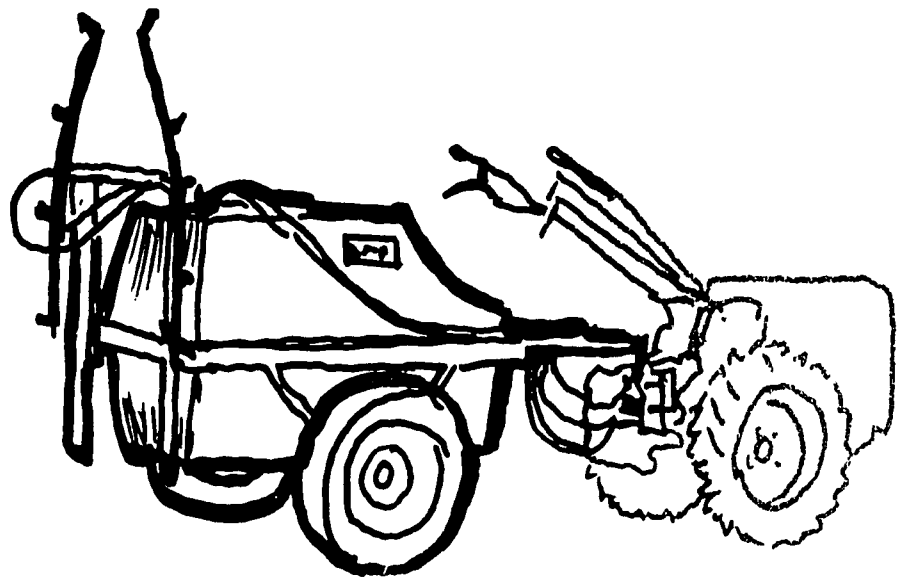
7.4 CONVERSION FACTORS

inches x 25.4	= millimeters
millimeters x 0.0394	= inches
feet x 0.3048	= meters
meters x 3.281	= feet
yards x 0.9144	= meters
meters x 1.094	= yards
miles x 1.609	= kilometers
kilometers x 0.6214	= miles
sq inches x 6.452	= sq centimeters
sq centimeters x 0.155	= sq inches
sq feet x 0.0929	= sq meters
sq meters x 10.764	= sq feet
sq yards x 0.836	= sq meters
sq meters x 1.196	= sq yards
acres x 0.4047	= hectares
hectares x 2.471	= acres
cu inches x 16.387	= cu centimeters
cu centimeters x 0.061	= cu inches
US quarts x 0.946	= liters
liters x 1.057	= US quarts
US gallons x 3.7854	= liters
liters x 0.2642	= US gallons
pounds x .4536	= kilograms
kilograms x 2.2046	= pounds
pounds per square inch x .0703	= kilograms per square centimeter
kilograms per square centimeter x 14.223	= pounds per square inch
horsepower x 0.745	= kilowatts
kilowatts x 1.341	= horsepower

7.4.1 TEMPERATURE

The factors for converting between centigrade (C) and fahrenheit (F) are:

centigrade to fahrenheit: $(^{\circ}6 \times 1.8) + 32 = {}^{\circ}F$
fahrenheit to centigrade: $(^{\circ}F - 32)0.5556 = {}^{\circ}C$



7.5 DATA TABLES

7.5.1 RATE OF TRAVEL

The elapsed time to travel a set distance indicates rate of travel, a factor that may be needed to determine application rates. The following chart provides rates of travel for various times to cover a set distance.

CHART 7-2

Rate of Travel

Travel Time for 200 feet	Rate in miles per hour	Travel Time for 100 meters	Rate in kilometers per hour
136 seconds	1	360 seconds	1
91 "	1.5	240 "	1.5
68 "	2	180 "	2
55 "	2.5	144 "	2.5
46 "	3	120 "	3
39 "	3.5	103 "	3.5
34 "	4	90 "	4
30 "	4.5	80 "	4.5
27 "	5	72 "	5

7.5.2 WEIGHT-VOLUME RELATIONSHIP

1 gm per		parts per million (PPM)	
1000 ml (1 liter)	=	1000 PPM	= 0.1%
10,000 ml (10 liters)	=	100 PPM	= 0.01%
100,000 ml (100 liters)	=	10 PPM	= 0.001%
1,000,000 ml (1000 liters)	=	1 PPM	= 0.0001%
10,000,000 ml (10,000 liters)	=	0.1 PPM	
100,000,000 ml (100,000 liters)	=	0.01 PPM	
1,000,000,000 ml (1,000,000 liters)	=	0.001 PPM or 1 PPB	

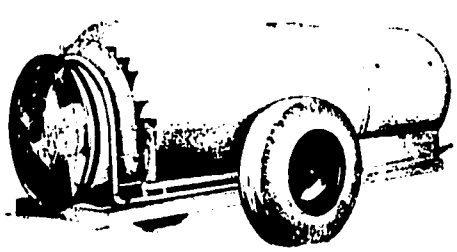
Temperature Conversion

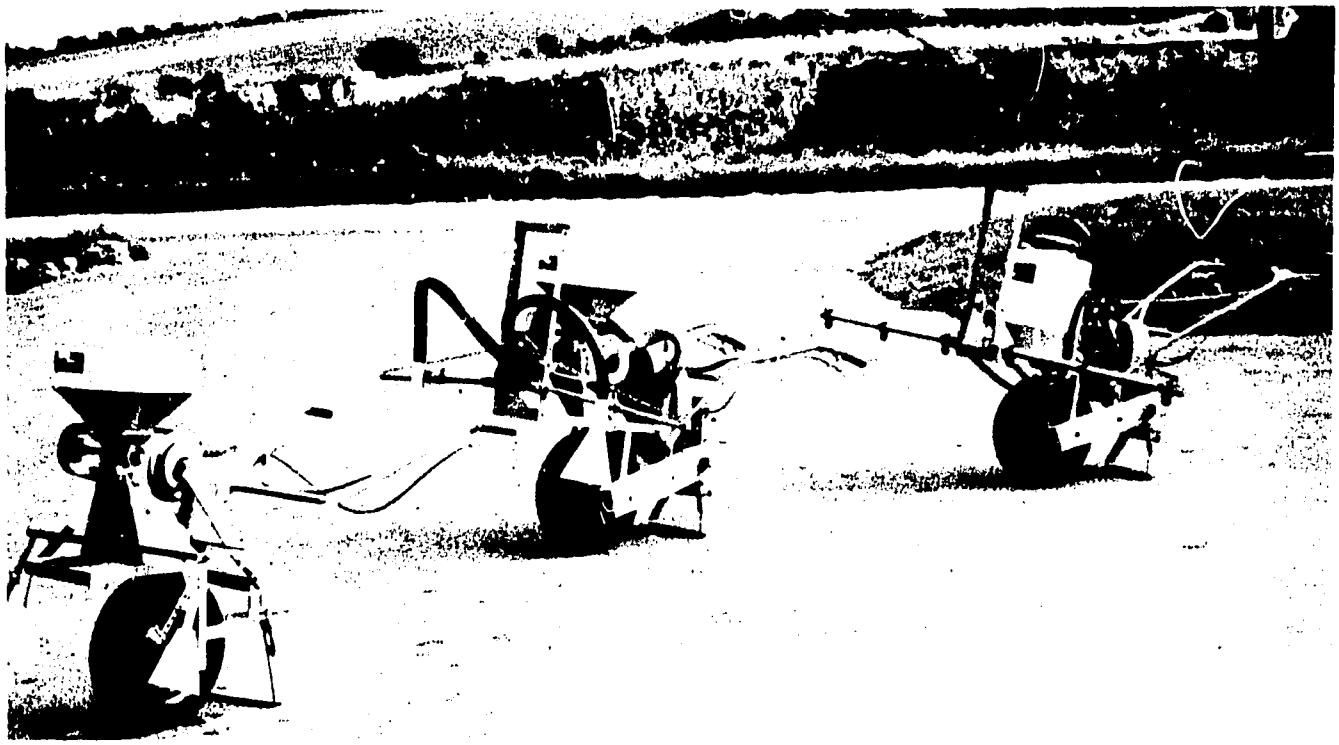
Degrees C = (Degrees F -32) x 0.5556

Degrees F = (Degrees C x 1.8) + 32

7.5.3 SPRAY CONCENTRATION CONVERSIONS

ounces per 100 gallons		PPM	% solution	grams per 100 liters
2/3		50	.005	5
1		75	.0075	7.5
1-1/3		100	.01	10
2	(1/8 lb.)	150	.015	15
2-2/3		200	.02	20
3-1/3		250	.025	25
4	(1/4 lb.)	300	.03	30
5-1/3		400	.04	40
6-2/3		500	.05	50
8	(1/2 lb.)	600	.06	60
9-1/3		700	.07	70
10-2/3		800	.08	80
12	(3/4 lb.)	900	.09	90
13-1/3		1000	0.10	100
16	(1 lb.)	1200	0.12	120
20	(1-1/4 lb.)	1500	0.15	150
24	(1-1/2 lb.)	1800	0.18	180



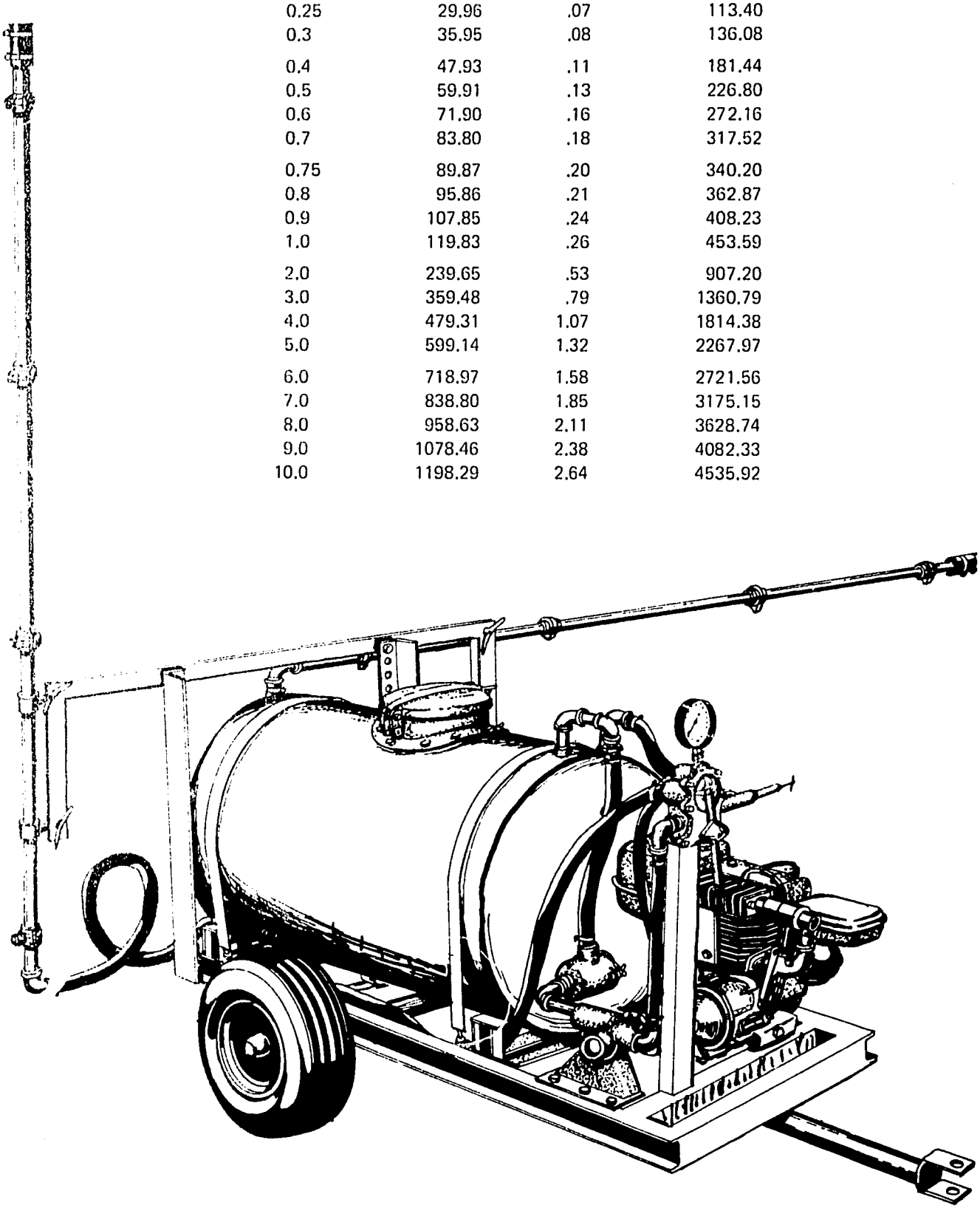


7.5.4 AREA EQUIVALENTS

square meters	square yards	square feet	square inches
.1	.1196	1.076	155.0
.25	.2990	2.691	387.5
.50	.5980	5.382	775.0
.75	.8970	8.073	1162.5
1.0	1.196	10.76	1550.0
2.0	2.392	21.53	3100.0
3.0	3.588	32.29	4650.0
4.0	4.784	43.06	6200.0
5.0	5.980	53.82	7750.0
6.0	7.176	64.58	9300.0
7.0	8.372	75.35	10850.0
8.0	9.568	86.11	12400.0
9.0	10.764	96.88	13950.0
10.0	11.960	107.64	15500.0
15.0	17.940	161.46	24000.0
20.0	23.920	215.27	31000.0
30.0	35.880	322.91	46499.9
40.0	47.840	430.55	61999.9
50.0	59.800	538.19	77499.8
60.0	71.760	645.83	92999.8
70.0	83.720	753.47	108499.8
80.0	95.680	861.11	123999.8
90.0	107.640	968.75	139499.7
100.0	119.600	1076.39	154999.69

7.5.5 EQUIVALENTS FOR VARIOUS CONCENTRATIONS

pounds per gallon US	grams per liter	pounds per liter	grams per gallon US
0.1	11.98	.03	45.36
0.2	23.97	.05	90.72
0.25	29.96	.07	113.40
0.3	35.95	.08	136.08
0.4	47.93	.11	181.44
0.5	59.91	.13	226.80
0.6	71.90	.16	272.16
0.7	83.80	.18	317.52
0.75	89.87	.20	340.20
0.8	95.86	.21	362.87
0.9	107.85	.24	408.23
1.0	119.83	.26	453.59
2.0	239.65	.53	907.20
3.0	359.48	.79	1360.79
4.0	479.31	1.07	1814.38
5.0	599.14	1.32	2267.97
6.0	718.97	1.58	2721.56
7.0	838.80	1.85	3175.15
8.0	958.63	2.11	3628.74
9.0	1078.46	2.38	4082.33
10.0	1198.29	2.64	4535.92



7.5.6 EQUIVALENT RATES FOR LIQUID APPLICATION

gallons US per acre	liters per hectare	gallons US per hectare	liters per acre	milliliters per square meter
.1	.935	.247	.379	.0935
.25	2.338	.618	.946	.234
.50	4.677	1.236	1.893	.468
.75	7.015	1.853	2.839	.702
1.0	9.354	2.471	3.785	.935
2.0	18.707	4.942	7.571	1.871
3.0	28.061	7.413	11.356	2.806
4.0	37.415	9.884	15.141	3.742
5.0	46.769	12.355	18.927	4.677
6.0	56.122	14.826	22.712	5.612
7.0	65.476	17.297	26.497	6.548
8.0	74.829	19.768	30.282	7.483
9.0	84.183	22.239	34.068	8.418
10.0	93.536	24.710	37.853	9.354
15.0	140.305	37.066	56.780	14.030
20.0	187.073	49.421	75.706	18.707
30.0	280.609	74.131	113.559	28.061
40.0	374.146	98.842	151.412	37.415
50.0	467.682	123.552	189.265	46.768
60.0	561.219	148.263	227.118	56.122
70.0	654.755	172.973	264.971	65.475
80.0	748.291	197.684	302.824	74.829
90.0	841.828	222.394	340.677	84.183
100.0	935.364	247.104	378.530	93.536

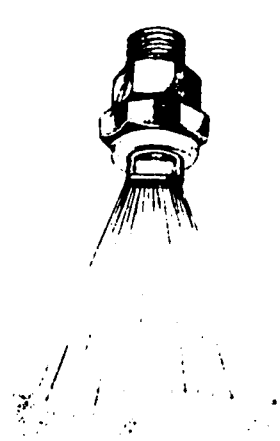
fluid ounces per 100 square feet	milliliters per 100 square feet	milliliters per square decameter	gallons US per acre	liters per hectare
.1	2.957	31.832	.340	3.183
.25	7.393	79.581	.850	7.957
.50	14.787	159.162	1.702	15.916
.75	22.180	238.743	2.552	23.874
1.0	29.573	318.324	3.403	31.832
2.0	59.147	636.649	6.806	63.663
3.0	88.720	954.973	10.209	95.495
4.0	118.294	1273.297	13.613	127.327
5.0	147.867	1591.621	17.016	159.158
6.0	177.440	1909.945	20.419	190.990
7.0	207.014	2228.270	23.822	222.821
8.0	236.587	2546.594	27.225	254.653
9.0	266.161	2864.918	30.628	286.485
10.0	295.734	3183.242	34.031	318.316
15.0	443.601	4774.864	51.047	477.474
20.0	591.468	6366.485	68.063	636.632
30.0	887.202	9549.727	102.094	954.948
40.0	1182.936	12732.969	136.125	1273.265
50.0	1478.670	15916.212	170.156	1591.581
60.0	1774.404	19099.454	204.188	1909.897
70.0	2070.138	22282.219	238.219	2228.213
80.0	2365.872	25465.939	272.250	2546.529
90.0	2661.606	28649.181	306.281	2864.845
100.0	2957.340	31832.423	340.313	3183.162

7.5.7 EQUIVALENT RATES FOR DRY MATERIAL APPLICATION

pounds per acre	kilograms per hectare	pounds per hectare	kilograms per acre
.1	.112	.25	.045
.25	.280	.62	.114
.50	.560	1.23	.227
.75	.841	1.85	.341
1.0	1.1209	2.47	.454
2.0	2.2417	4.94	.907
3.0	3.3626	7.31	1.361
4.0	4.4834	9.88	1.814
5.0	5.6043	12.35	2.268
6.0	6.7251	14.83	2.722
7.0	7.8460	17.30	3.175
8.0	8.9669	19.72	3.629
9.0	10.8077	22.24	4.082
10.0	11.2086	24.71	4.536
15.0	16.2129	37.07	6.804
20.0	22.4170	49.42	9.071
30.0	33.6256	74.15	13.607
40.0	44.8342	98.84	18.143
50.0	56.0428	123.55	22.679
60.0	67.2514	148.26	27.215
70.0	78.4600	172.97	31.751
80.0	89.6686	197.68	36.287
90.0	100.8772	222.39	40.823
100.0	112.0858	247.10	45.359

kilograms per hectare	pounds per acre	pounds per hectare	kilograms per acre
.1	.09	.2205	.0405
.25	.22	.5512	.1012
.50	.45	1.1023	.2023
.75	.67	1.6535	.3035
1.0	.89	2.2046	.405
2.0	1.8	4.4092	.809
3.0	2.7	6.6138	1.214
4.0	3.6	8.8184	1.619
5.0	4.5	11.0230	2.023
6.0	5.3	13.2276	2.428
7.0	6.2	15.4322	2.833
8.0	7.1	17.6368	3.238
9.0	8.0	19.8414	3.642
10.0	8.9	22.0460	4.047
15.0	12.5	33.0690	6.070
20.0	17.8	44.0920	8.093
30.0	26.8	66.1380	12.140
40.0	35.7	88.1840	16.187
50.0	44.6	110.2300	20.234
60.0	53.5	132.2760	24.281
70.0	62.5	154.3220	28.328
80.0	71.4	176.3680	32.375
90.0	80.3	198.4140	36.422
100.0	89.2	220.4600	40.4687

7.5.8 GRAMS OF TREATMENT REQUIRED AT VARIOUS RATES FOR INDICATED AREAS

Rate in pounds per acre (product or ai basis)

Area treated square feet	0.25	0.50	1	2	3	4	5	6	7.5	8	9	10
6	0.02	0.03	0.06	0.13	0.19	0.25	0.31	0.38	0.47	0.50	0.56	0.63
10	0.03	0.05	0.10	0.21	0.31	0.42	0.52	0.63	0.78	0.83	0.94	1.04
25	0.07	0.13	0.26	0.52	0.78	1.04	1.30	1.56	1.95	2.08	2.34	2.60
30	0.08	0.16	0.31	0.63	0.94	1.25	1.56	1.87	2.34	2.50	2.81	3.12
36	0.09	0.19	0.38	0.75	1.13	1.50	1.87	2.25	2.81	3.00	3.37	3.75
48	0.13	0.25	0.50	1.00	1.50	2.00	2.50	3.00	3.75	4.00	4.50	5.00
64	0.17	0.33	0.67	1.33	2.00	2.67	3.33	4.00	5.00	5.33	6.00	6.66
72	0.19	0.38	0.75	1.50	2.25	3.00	3.75	4.50	5.62	6.00	6.75	7.50
75	0.20	0.39	0.78	1.56	2.34	3.12	3.91	4.69	5.86	6.25	7.03	7.81
81	0.21	0.42	0.84	1.69	2.53	3.37	4.22	5.06	6.33	6.75	7.59	8.44
90	0.23	0.47	0.94	1.87	2.81	3.75	4.69	5.62	7.03	7.50	8.44	9.37
100	0.26	0.52	1.04	2.08	3.12	4.17	5.21	6.25	7.81	8.33	9.37	10.4
120	0.31	0.63	1.25	2.50	3.75	5.00	6.25	7.50	9.37	10.0	11.3	12.5
150	0.39	0.78	1.56	3.12	4.69	6.25	7.81	9.37	11.7	12.5	14.1	15.6
200	0.52	1.04	2.08	4.17	6.25	8.33	10.4	12.5	15.6	16.7	18.7	20.8
250	0.65	1.30	2.60	5.21	7.81	10.4	13.0	15.6	19.5	20.8	23.4	26.0
300	0.78	1.56	3.12	6.25	9.37	12.5	15.6	18.7	23.4	25.0	28.1	31.2
400	1.04	2.08	4.17	8.33	12.5	16.7	20.8	25.0	31.2	33.3	37.5	41.7
500	1.30	2.60	5.21	10.4	15.6	20.8	26.0	31.2	39.1	41.7	46.9	52.1
750	1.95	3.91	7.81	15.6	23.4	31.2	39.1	46.9	58.6	62.5	70.3	78.1
1000	2.60	5.21	10.4	20.8	31.2	41.7	52.1	62.5	78.1	83.3	93.7	104
1200	3.12	6.25	12.5	25.0	37.5	50.0	62.5	75.0	93.7	100	113	125