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Demonstration and Research Pest Control

Category 10

Missouri Manual 91

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About this manual

This manual was prepared for use in Missouri's Pesticide Applicator Training Program and is intended to provide the information needed to meet the minimum Environmental Protection Agency (EPA) standards for certification of commercial applicators in Category 10 — Demonstration and Research Pest Control — under the Federal Insecticide, Fungicide, and Rodenticide Act and the Missouri Pesticide Use Act. It also prepares trainees for an examination, based on this manual, administered by the Missouri Department of Agriculture. In addition to the material covered in the manual, trainees will be responsible for information contained in one or more of the 13 category manuals that are appropriate for a particular pest control activity.

This manual **does not** provide all of the information you need for safe and effective use of pesticides. Examine the label for each pesticide you use. Labels must list directions, precautions, and health information — all of which are updated regularly when a pesticide is registered for use in Missouri. If information on a current pesticide label conflicts with information in this manual, follow the label.

Manufacturers will supply additional information about products registered for use in Missouri. Information is also available from the Office of the Pesticide Coordinator, 212 Waters Hall, University of Missouri-Columbia, Columbia, MO 65211, or phone (573)884-6361.

Missouri's Pesticide Applicator Training Program is a cooperative effort. The Missouri Department of Agriculture is the state lead agency. MU Extension at the University of Missouri-Columbia is responsible for the content of the training program. The EPA and the Missouri departments of Conservation, Health, Natural Resources, and Transportation also contribute to the development of educational materials and participate in the training program.

Note: Terms highlighted in boldface type throughout the text are defined in the glossary.

Credits: This manual was adapted from pesticide applicator training manuals from the Universities of Georgia and Illinois and from Iowa State University.

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Pesticide development

Use of toxic chemicals to control pests is not new; the Greek poet Homer mentioned the value of burning sulfur as a **fumigant** about 1000 B.C. Arsenic was used as an **insecticide** a century before the birth of Christ.

The first so-called natural insecticide was tobacco. It was in use at least 300 years ago. Today we know that tobacco was effective because of nicotine, which is still being used in a few insecticides.

Most early **pesticides** were discovered by accident. Bordeaux mixture, a weapon against plant disease, is an interesting example. The owner of a small vineyard near Bordeaux, France, mixed lime, copper sulfate, and water and splashed the bluish mixture on grape vines near a path that crossed his property. He was trying to discourage schoolboy "pests" from picking his fruit by making it look unappetizing. Later, the vineyard was stricken by powdery mildew, but the vines that had been "treated" survived.

By the middle of the nineteenth century, the first scientific studies of pesticides were appearing. Experimentation with arsenical compounds led to the introduction of Paris green, which was used to check the spread of the Colorado potato beetle. It was so successful that it was the most widely used agricultural insecticide for many years.

Near the end of the nineteenth century, a vineyard operator, using Bordeaux mixture on his grapes, noticed that the **fungicide** caused the leaves of certain weeds to turn black. The idea of **selective herbicides** may have developed from this chance observation.

Another early **herbicide** was iron sulfate. If sprayed on a mixture of cereal plants and broadleaf weeds, it kills the weeds but not the small grain.

Use of pesticides expanded shortly before World War II. That increased use was a factor contributing to the dramatic increase in farming efficiency at that time.

Further advances were made during the war. DDT was discovered in Switzerland, **organophosphorous compounds** were introduced in Germany, and **dithiocarbamate fungicides** were discovered in the United States. The discovery that **organochlorine compounds** made effective pesticides followed. The great potential of DDT was not appreciated until its use played a part in controlling a severe outbreak of typhus. Organophosphorous and organochlorine compounds of many kinds have since been used as pesticides.

Research also led to the introduction of herbicides that affected plants somewhat like natural **growth regulators** (hormones). Early herbicides of this type included 2,4-D and MCPA.

The development and use of pesticides expanded rapidly after World War II. The increased use led to concerns about safety and long-term effects of chemicals. These concerns were heightened by publication of the book *Silent Spring*. More recently, there has been widespread concern and press discussion about exposure of Vietnam era veterans to "Agent Orange," a **defoliant** mixture that included 2,4,5-T. These concerns resulted in new laws and regulations controlling pesticide use and the removal of some pesticides, notably DDT, from the market.

Methods of pest control

Modern pest control is a sophisticated discipline. The technology used is complex, and its implementation requires a complete and thorough understanding of the many environmental parameters that interact with pest control practices. Solutions for today's pest problems must be based on factual information and on scientific principles and philosophies. Practitioners must realize that there is more to solving pest problems than simply being able to list methods. Each component of the integrated pest management system should be analyzed to plan an integrated program.

The scientific approach to pest control involves the following major components: (1) a thorough understanding of the overall objectives of pest management, (2) a step-by-step program that can be followed in dealing with a pest problem, and (3) a realistic appraisal of the limitations and potentials of individual available technologies.

Pest control can be approached on either a hit-or-miss basis or as a carefully planned and coordinated program. The second alternative is most likely to be successful. A well-planned, properly executed program consists of various appropriate techniques or methods coordinated in a sequence from the initiation of the first crop management operation until the growing season is over.

To aid in establishing an effective program, you may consider a four-step approach consisting of problem diagnosis, method evaluation, program selection and program execution. These steps should be well in mind whenever a program is planned. The major components of each step are outlined below.

I. Problem diagnosis

The first logical step in designing a program is to itemize and evaluate pest problems and other important factors that interact with pest control practices. The factors listed here probably do not include all of the possibilities that should be considered during diagnosis; they do include many of the important ones, and they illustrate the scope of items you must consider when attacking pest problems.

A. Pest presence

1. Pest identification

Identification of the pest(s) almost always is required. Because pests differ in their growth habit, reproductive method, type of problem caused, and response to individual control methods, different practices may have to be used for different species. Many sources of information are available to assist you in properly identifying pests.

2. Pest abundance

The relative abundance and economic importance of each species in the field should be determined and a priority list of pests to receive treatment should be established. Treatment plans should include not only those species causing the current economic damage but also those present in small numbers that may become economically important at a later time.

3. New pests

Serious pests invading a new area must be recognized. In this situation, a preventive program may be desired. The assumption that extremely serious pests can be readily controlled with modern control practices is false.

B. Soil

Understanding soils is most important when working with soil-applied pesticides.

1. Texture

Soil texture (sand, silt, and clay) determines such properties as tilth, water-holding capacity, rate of water and pesticide movement, and the ability to work with various tillage equipment types and systems.

2. Soil conditions

Soil conditions at the time of planting, tilling, or pesticide application are important. Excessive surface moisture, residues, surface unevenness, and cloddiness can all impair the effectiveness of soil-applied pesticides. Different soil types within the same field can limit the choice of suitable pesticides; this limitation is particularly true for strongly bound pesticides. Soil moisture can affect **foliar-applied herbicide** performance because plants under water stress tend to be more tolerant.

3. Colloidal components

Clay and organic matter are the **colloidal fractions** in which most of the surface reactions characteristic of soils take place. Soils high in organic matter may bind certain pesticides so tightly that they may not be effective. On the other hand, soils having both low organic matter and clay content may permit excessive pesticide leaching or may lack sufficient **adsorptive surfaces** to prevent crop injury.

4. pH

The pH of a soil determines the degree of **ionization** of some herbicides and thus their binding affinities and availability for weed control.

C. Environmental factors

1. Soil erosion potential

The potential for a soil to erode determines the amount of surface residue that should be left on the soil surface. This factor affects the types of acceptable tillage, and in turn, the number and type of chemical pest control options.

2. Nontarget species

The presence of sensitive crops in an area may necessitate adjustments in choice of pesticide and application techniques or timing to minimize chances of injury. This holds particularly true for herbicide use.

3. Nontarget sites

The proximity of bodies of water may affect the choice of pest control techniques.

D. Crop management systems

1. Tillage and other practices

Type and frequency of tillage, mowing, grazing, and crop rotation all determine what management is proper and which pest control practices can be used. In many instances, the management system is the major pest control tool employed. This is true for turf, forage crops, and pastures, all cases in which mismanagement often leads to increased pest problems.

2. Minimum-tillage systems

The loss of tillage can limit the number of control techniques available.

3. Cropping sequences

The previous cropping sequence and desired future sequence must be taken into account, particularly when long-lived herbicides are used in a program and a sensitive crop is involved. Cropping sequence also must be considered when a problem pest appears and effective control of it can be better obtained in some crops than in others.

E. Past pest control programs and results

Past experience should serve as a basis for current choices. Those practices that have worked consistently well should be retained. Those that have given poor results should be scrutinized and replaced if lack of effectiveness cannot be overcome.

II. Method evaluation

Evaluation of currently available control methods is the second logical step in devising a program. You will need to draw on your own experiences and consult educational literature and others experienced in the field. Evaluate all practices that will provide pest control, including not only individual pesticides but the benefits that other management practices can bring to the program. Evaluate each practice for the following information:

A. Effectiveness

Determining the effectiveness of each method to control each pest species present is essential.

B. Consistency

How consistent is the outcome? Can acceptable results be expected each time the method is used or does it sometimes give incomplete results?

C. Fit within the individual program

Ascertaining the potential for integrating the practice into both crop management and pest development sequences is important.

D. Flexibility

How flexible is the practice with regard to timing? Methods that must be conducted within a short time (e.g., treatments or operations restricted to a few days during the early stages of crop development) are not as dependable as those that can be used over long periods or that can be accomplished along with an essential management practice (e.g., treatments at planting time).

III. Program selection

Select those practices that provide a pest control program that is effective, economical, and flexible. The goal is to provide a multi-component program that will fit the specific pest situation rather than to depend on a single practice that may or may not be effective. In designing an overall program, take the following aspects into consideration:

A. Economics

The cost of the individual components of the program must be weighed against probable economic returns.

B. The management system

The program must fit both the individual management system and the capabilities of the user.

1. Equipment

Is sufficient equipment available when it is needed to accomplish the various steps?

2. Custom services

Can custom applicators be relied on to conduct essential parts of the program?

3. Time

Will sufficient time be available during critical peak work periods? This requirement is particularly important when a practice is effective only if conducted within a short interval.

4. Operational capability

Does the managerial and worker staff have the capability and experience to carry out the program?

5. Crop and management system

Do the steps fit into the cropping and management system?

C. Appropriate follow-up

1. Evaluation and follow-up measures

Once the program is under way, fields should be inspected periodically and appropriate pest control methods should be taken when necessary.

2. Evaluation and documentation for diagnosis and planning in subsequent seasons.

Factors that should be recorded include problem spots in the field, new pests, soil and weather conditions before, during, and after pesticide applications have been made, size and stage of development of the crop and pest at time treatments are applied, and general crop vigor.

IV. Program execution

If a program is not properly and efficiently conducted, diagnosis, method evaluation, and program selection efforts will be wasted. Three factors are essential: operations must be done at the right time, proper equipment must be employed, and equipment must be correctly maintained, adjusted, and operated.

Pesticide-organism interactions

Both beneficial and harmful effects of pesticides are determined by pesticide-organism interactions or how pesticides and organisms react to each other. To do its job, a pesticide must (1) penetrate the organism, (2) move or be transported to the site of action, and (3) there disrupt or alter a vital function. The manner in which the pesticide affects the vital function is called its **mode of action**. Penetration, transport, and mode of action involve pesticide-organism interactions. Pesticide-organism interactions also are involved in the **metabolism**, accumulation, and elimination of pesticides by the organism as well as in **biodegradation** and **biological magnification**.

Pesticide selectivity and the development of pesticide **resistance** are often caused by differences in pesticide-organism interactions. Selectivity is the ability of a pesticide to kill or otherwise alter one organism and not another. Resistance is the inherent ability of a pest to sustain less damage from pesticide application than other individuals of that species under comparable environmental conditions. Insects and mites present many examples of resistance to pesticides worldwide. In the early 1990s, more than 500 species of arthropods were known to be resistant to insecticides. Pesticide resistance is not limited to arthropods; there are at least 200 species of fungi, over 200 species of weeds, and several species of nematodes and rodents also resistant to one or more pesticides. Common waterhemp with resistance to **acetolactate synthase-inhibiting** (ALS-inhibiting) herbicides is common in the Midwest. Resistance often develops in pest populations that have been frequently treated with a single pesticide. Development of resistance in pest populations may sometimes be averted or delayed by reducing the number of treatments and alternating the type of pesticides used.

Penetration

The speed and extent of penetration depends on the permeability of the organism to the specific pesticide. This permeability differs significantly among plants and insects and even among different tissues of the same organism. Among animals, tissues of the respiratory and digestive system are usually much more **permeable** than the skin. With plants, hardened growth and bark generally provide a more effective barrier than new and succulent growth. The ability of a pesticide to penetrate an organism depends on its chemical nature and the formulation. Penetration is usually increased by organic solvents.

Transport

The movement of a pesticide from the place where it entered an organism to its site of action involves the mobility of the pesticide molecules and the efficiency of the transporting mechanism of the plant or animal, i.e., how quickly the pesticide moves through the plant or animal's system. **Systemic herbicides** must move through the plant to areas of interaction. Other herbicides are not mobile in the plant and affect only the area with which they are in direct contact.

Mode of action

A pesticide performs its main function only after it reaches action sites within an organism. These sites are usually the **protoplasm** of living cells and often particular kinds of cells. For example, the cells targeted by organophosphate insecticides are the nerve cells. The herbicide atrazine affects **photosynthesis** in the **chloroplasts** of susceptible plant cells.

Pesticides kill or otherwise alter an organism by disrupting or interfering with some vital physiological function. This is known as the pesticide's mode of action. The mode of action of organophosphate insecticides (e.g., methyl parathion, malathion, Thimet®) is inhibition of the breakdown of **acetylcholine** by **cholinesterase**, an **enzyme** that is essential in regulating the proper functioning of the nervous system. When acetylcholine accumulates, muscles and glands become overactive because of excessive stimulation of the nerve cells. Some herbicides act as plant growth regulators, speeding up or slowing down cell growth and reproduction; other herbicides may target vital plant functions or specific enzymes. For example, one major class of herbicides, the ALS inhibitors, blocks the synthesis of an enzyme that is critical to the production of several **amino acids** within the plant. Fungicides may act as inhibitors of spore germination and fungal growth.

Metabolism

Metabolism is the process by which a pesticide, or other chemical, is changed into one or more different chemicals within a living organism. The metabolic product, or **metabolite**, may be either more toxic or less toxic than the original pesticide ingredient. Aldicarb, the active ingredient in Temik®, has metabolites that are equally toxic or slightly less so. Some pesticides are effective only after they have been metabolized to a lethal compound by an organism. For example, 2,4-DB is changed rapidly to 2,4-D by broadleaf plants other than legumes. Actually 2,4-DB is relatively harmless to the plant in itself. Enzymes of susceptible broadleaf plants alter the compound, leaving the toxic 2,4-D. Given enough time, an organism may be able to metabolize certain pesticides to their nontoxic metabolites. Survival may depend on whether or not the organism can metabolize the pesticide into nontoxic metabolites before the toxic activity is complete or irreversible.

Accumulation, elimination and detoxification

Pesticide chemicals and their metabolites may be stored or accumulated within an organism or be eliminated as waste. If the level of exposure to most accumulated pesticides remains constant, an equilibrium between storage, metabolism, and elimination is reached, and the concentration of the pesticide and its metabolites remains constant within an organism. If the level of exposure is changed, the concentration within an organism correspondingly increases or decreases.

Because pesticide residues may accumulate within organisms, special precautions in harvest or slaughter must be observed with the treated commodities. Grazing, harvest, slaughter restrictions, and freshening intervals provide the necessary time for metabolites to be detoxified or eliminated before safe consumption of the treated product is allowed.

Biodegradation

Pesticides in the environment can be affected by

- soil organic matter
- soil pH
- soil texture
- ultraviolet light
- soil microorganisms
- soil moisture
- temperature
- humidity

These factors not only affect the efficacy of a pesticide but also determine the manner and rate of its metabolization. Biodegradation is simply metabolism, but it more specifically refers to the decomposition of pesticide residues in the environment by bacteria and other microorganisms that use the residues as nutrient sources.

Biological magnification

Biological magnification is the tendency for certain pesticides to become progressively more concentrated in each type of organism when moving from the bottom to the top organism in a food chain. An example of biological magnification is when birds of prey become sick after feeding on an animal that is dead or dying from acute exposure to a pesticide. Perhaps the most familiar example of reproductive effects of pesticides on nontarget organisms is the thinning of the eggshells of birds exposed to certain organochlorine insecticides such as DDT. This eggshell thinning may have been initiated by a chain of events beginning when invertebrates that consumed plants with DDT residues were, in turn, eaten by rodents, reptiles, amphibians, fish, and insectivores, further concentrating the residues in their fat tissues. These intermediate predators in the food chain were eaten by the top predators, which then received yet higher insecticide concentrations. Fortunately, the organochlorines have been banned for a number of years, and such biological magnification problems have reversed themselves. Top predators are again increasing in number. Recently, the bald eagle was removed from the endangered species list because the reproductive capacity of the population is increasing. Thus, awareness of such pesticide-organism interactions is important when working with certain pesticides.

Pesticide interactions

Today most agricultural chemicals are applied in mixtures, and the use of mixtures is expected to grow. During a season, crops commonly receive multiple seed treatments, **preemergence** and **postemergence herbicides**, fungicides, **nematicides**, insecticides, and sometimes plant growth regulators. Most agricultural chemicals degrade rapidly and do not interact with other chemicals, but some do persist and interact with chemicals that are already present or that will be applied sequentially.

Most pesticide interactions involve herbicides. Herbicidal interactions can be divided into two groups: (a) interactions with other herbicidal chemicals, and (b) interactions with nonherbicidal chemicals. Most simply, these interactions result in three possible outcomes: (a) greater than expected **phytotoxicity**, (b) the expected response, and (c) less than expected phytotoxicity. **Synergism** occurs when the plant response is greater than expected; **antagonism** occurs when the plant response is less than expected.

A common interaction with a herbicide is that of a herbicide synergist. Herbicide synergists are nonherbicides used to increase the phytotoxicity of a herbicide by a physiological mechanism. These chemicals have no significant phytotoxicity singly on the specific plant species. A synergist's mode of action can be through increased uptake of a herbicide, the prevention of its deactivation, or something more complex. A synergist can be a nonphytotoxic adjuvant such as a crop oil or surfactant.

Another example of a nonherbicidal compound that interacts is that of a herbicide **antidote**. Like a synergist, the antidote is a chemical that by itself has no significant herbicidal activity on a given plant species. When mixed with a particular herbicide or herbicide mixture, it decreases phytotoxicity. Antidotes are used to protect crops from herbicide injury. A common example is the use of seed treatments to protect grain sorghum from **chloroacetamide herbicide** injury.

Research has shown that phytotoxic interactions between major pesticide groups are infrequent, but not rare. The use of insecticides with herbicides can increase or decrease the herbicidal activity. Most herbicide-insecticide mixtures result in increased crop injury. Although not as common, herbicidal interaction with fungicides is generally antagonistic.

Equipment calibration

Correct **calibration** and accurate measuring and mixing of pesticides are extremely important in demonstration and research pest control work. Although the hazards of application may be reduced and the chances of nontarget pollution minimized in small-plot work, the probability of applying a pesticide at the wrong rate is generally greater in small-plots than in large ones. Small errors in measuring the experimental material, for example, may cause over- or under-dosing of the treatment plot. The addition of 2 fluid ounces of a herbicide in a 100-gallon tank of water during mixing for general field application may not be significant. However, this small amount added to 2 quarts of water in small-plot research can produce highly inaccurate results.

Small-plot experiments often demand that the researcher work with measurements of grams, milliliters, or ounces rather than pints or pounds. Rough estimates or "rounding-off" in measuring pesticides for demonstration and research is not an acceptable practice.

Liquid measurements should be made with graduated cylinders or pipettes. Automatic dispensers should be used with pipettes to avoid getting the pesticide into the researcher's mouth.

Dry materials should be measured on properly adjusted scales that provide measurements in milligrams, grams, or ounces. Conversion tables are provided in Appendix A.

Because demonstration and research plots are often relatively small, hand-held equipment is often used in applying pesticides to them. Small-plot equipment, most commonly hand-held, CO_2-powered backpack sprayers, must be calibrated to give the precise applications required and to guarantee accurate results in research. Small sprayers can be calibrated by using the following method:

1. Based on the manufacturer's broadcast recommendations on gallons per acre (gpa) application rates, and on nozzle type for the specific situation, select a suitable spray tip size from catalogs. Note information on various combinations of pressure, nozzle spacing, ground speed, spray angle, and the gallons per minute (gpm) or gpa delivered for the nozzle tip.

2. Select the ground speed based on what you consider to be a comfortable operating speed. A common speed is 3 miles per hour (mph) for plot work with hand-held sprayers. Use the following table to determine ground speed:

Sprayer ground speed in mph	Time required in seconds to travel 100 feet
1	68
2	34
3	23
4	17
5	14

3. At this point, the nozzle type, tip size, angle, spacing, pressure, and sprayer speed that closely deliver the recommended gpa rate have been established. Now determine the actual spray delivery in gpm or gpa output by collecting the output from a nozzle over a timed period and by using one of the following formulas. For the greatest accuracy, use a graduated cylinder to collect the sprayer output.

$$\text{gpm} = \frac{\text{gpa x mph x W}}{5{,}940} \qquad \text{gpa} = \frac{\text{5,940 x gpm (per nozzle)}}{\text{mph x W}}$$

where W = spacing between nozzles in inches and 5,940 is a constant used in sprayer calibration calculations. If using a single nozzle, W is the spray band width in inches.

milliliters per minute ÷ 3,785 ml/gal = gpm

Note: Output can be collected for less than a minute.

Example: If 180 ml is collected in 30 sec, what is the output in ml/min? In gpm?

Answer: 180 ml ÷ 30 sec = 6 ml/sec x 60 sec/min
= 360 ml/min

360 ml/min ÷ 3,785 ml/gal = 0.095 gpm

4. Sample calculations using gpm and gpa formulas

If your goal is to apply 30 gpa using a CO2 backpack sprayer with a 4-nozzle boom with 20-inch nozzle spacing while walking at 3 mph, how many milliliters should be collected in 30 sec?

$$\text{gpm} = \frac{\text{30 gpa x 3 mph x 20 in.}}{5{,}940} = 0.3 \text{ gpm}$$

0.3 gpm x 3,785 ml/gal = 1,147 ml/min

1,147 ml/min ÷ 2 = 573.5 ml/30 sec

If you collect 0.25 gpm from one nozzle using the same variables as above, what is the sprayer's gpa rate?

$$\text{gpa} = \frac{\text{5,940 x 0.25 gpm}}{\text{3 mph x 20 in.}} = \text{24.75 gpa delivered}$$

More information and examples on calibration are provided in MU publications MX328, *Applying Pesticides Correctly*; G1270, *Calibrating Field Sprayers;* G1272, *Spray Mix Calculations;* and G1273, *Calibrating Granular Pesticide Applicators.*

5. For final adjustments, check all nozzles for uniform output. Replace a nozzle if the amount it delivers varies more than 5 percent from the average output of all the nozzles on the boom. Slight adjust-

ments in pressure or variation in ground speed can fine tune the output to the desired amount. For major changes in spray output, replace nozzle tips.

Record keeping

Certified commercial and noncommercial applicators and public operators must comply with the Missouri Pesticide Use Act in maintaining records for the use of pesticides. Certified commercial applicators or their employers must keep and maintain records for the use of any pesticide(s). Certified noncommercial applicators and certified public operators or their employers must keep and maintain records for the use of restricted-use pesticides. The records must be kept for three years following the date of application. Maintaining accurate pesticide application records is important for safe and effective pest management. Record the following information for all applications of **restricted-use pesticides**:

- Name and license number of the certified applicator or operator.
- Name of the noncertified applicator or the name and license number of the pesticide technician using pesticide(s), if applicable.
- Application date.
- Name and address of the person requesting the pesticide use if applicable.
- Address or brief description of the application site.
- Pest(s) controlled or prevented by the pesticide application.
- Complete trade (manufacturer's brand) name(s) from the label(s) of the pesticide(s).
- The U.S. EPA registration number(s) from the label(s) of the pesticide(s).
- A reasonable estimate of the amount of pesticide(s) applied and, if applicable, the actual rate of application expressed in reasonable and understandable terms.
- A reasonable estimate of the time, air temperature, and average wind speed and direction at the site of outdoor pesticide applications, excluding applications of pesticides in general structural pest control and termite pest control within 10 feet of a building.

In addition, applicators may find it useful to keep records of the following information:

- Crop and variety planted or animals treated.
- Crop history, including planting date and developmental stage.
- Percent active ingredient, type of formulation, manufacturer and purchase date.
- Calibration of equipment, including nozzle size, boom height, gpa and pressure.
- Additional weather conditions, including soil moisture and temperature, cloud cover, and relative humidity.
- Total cost of the application.
- Treatment time of animals, and their average weight.
- Application results.

Experimental-use permits

An experimental-use permit allows limited field testing of an unregistered pesticide or of a registered pesticide for an unapproved use. The permit allows limited field testing to gather data on efficacy and safety in support of application to register the pesticide or expand the label. Experimental-use permits facilitate developing new, less hazardous pesticides while providing sufficient regulatory control to protect human health and the environment. Permits are issued by the EPA's Office of Pesticide Programs on a temporary basis. Application for an experimental-use permit should be submitted to the Document Processing Desk (EUP), Office of Pesticide Programs (H7504C), U.S. Environmental Protection Agency, 401 M Street, S.W., Washington, DC 20460, at least 90 days prior to the intended date of shipment or use. If the application of an experimental pesticide could result in any residue on or in food or feed, the Office of Pesticide Programs will set a temporary tolerance or safe residue level before issuing a permit.

Experimental-use permits are not required for pesticides undergoing the following tests:

- Laboratory or greenhouse tests.
- Field tests of less than 10 acres.
- Aquatic tests of not more than one surface-acre of water.
- Experimental animal tests.

All field crops treated with experimental pesticides must be destroyed or consumed by experimental animals unless a tolerance has been established.

Field experiments and demonstrations

Good demonstrations and research experiments can be of great value; poor demonstrations and experiments can be worthless or even misleading. In deciding whether to designate a project as a demonstration or research, project planners need to keep in mind the audience for whom the work is being done and what would be appropriate that particular audience. The difference lies in the purposes of the activities: demonstrations seek to communicate and persuade, whereas research seeks to answer a question. Research involves collecting data from experiments that are replicated and include randomized treatments. Demonstrations do not have to be replicated nor do they need to have controls; thus, they are not valid experiments. They also do not sample the variation within the test area. Such trials are not acceptable for publication of data or sales promotion but may be valuable to demonstrate an idea or management option.

Demonstrations

Demonstrations must be visually convincing, but they do not necessarily include data collection or analysis. They are usually short-term, unreplicated projects conducted at one site. For these reasons, demonstrations tend to be easier and less expensive to conduct than research. They can stimulate producers to think about different management practices as well as convey simple recommendations. The results of demonstrations are of more restricted use than those of research because there is no way to measure their limits of confidence. Demonstrations are usually one of two types or a combination of the two: method demonstrations or result demonstrations. Method demonstrations show how to do something, e.g., how to calibrate a sprayer or incorporate a herbicide properly into the soil. Result demonstrations show by example (generally to the producer) the practical application of an established fact. This type of demonstration is commonly used as a training tool in the Cooperative Extension Service.

Research

Research involves a systematic method designed to discover facts or principles. Most research is conducted by using the following sequence of steps:

- Formulating a hypothesis — a suggested solution or explanation.
- Designing an experiment to test the hypothesis objectively.
- Collecting data.
- Interpreting data.
- Accepting, rejecting, or altering the original hypothesis.

Before conducting a field experiment with pesticides, it is best to prepare a statement that answers the following questions:

- What are the objectives? (What do you want to prove?)
- What is the design? (How are the treatments and plots arranged?)
- What variables exist within either the experiment or the plot area? (Are there soil or varietal differences?)
- How many replications are needed?
- What is the sampling procedure? (Number of weeds per square foot, yield, etc.)
- How will the data be analyzed?
- How will the results of the experiment be used? (Publication, sales or demonstration?)

The importance of the last question cannot be overemphasized. The intended use of the data collected in the experiment will greatly affect the answers to other questions. For example, an experiment designed to show that the yield increase was due to pesticide use will involve a different experimental plot design, a greater number of replications and a different sampling procedure than an experiment designed to illustrate the possible use of a pesticide in combination with a new tillage practice.

A well-thought-out experiment should be simple and precise and contain no systematic error (e.g., all of the plots receiving one treatment should not differ systematically from the plots receiving another treatment). The researcher should follow the scientific method meticulously when designing an experiment. It is important to realize, however, that no answer is absolute and that all generalizations drawn from an experiment should be made with care.

Experimental error and bias are inherent in any experiment; therefore, a primary goal of the researcher is to reduce these influences to a minimum. Good experimental technique goes a long way toward minimizing error and bias. Every effort should be made to

- Apply all treatments uniformly.
- Measure all treatment effects in an unbiased way.
- Prevent gross errors.
- Control external influences so that all treatments are affected equally.

Replication and randomization

Replication and randomization are basic components of valid research experiments. They function to decrease experimental error and provide validity to the data obtained from the experiment. Field experiments are commonly replicated three or four times. For example, an experiment to test three herbicide treatments and a control would contain 12 plots if replicated three times. Many field experiments are repeated over a number of years or at several locations. These also may be considered broad forms of replication.

By replicating an experiment, researchers are able to estimate the amount of experimental error in the study and improve the precision of the results. The number of replications required in a particular experiment depends on the magnitude of the differences the researcher wishes to detect and the variability of the data. Careful consideration of the number of replications at the beginning of the experiment can save much frustration later.

The assignment of treatments to plots in a purely objective (random) manner is called randomization. Every treatment should have an equal chance of being assigned to any experimental unit. This ensures a valid and unbiased estimate of the experimental error and treatment differences.

Control or check plots

The experimental units or plots to which the treatment is not given are called the controls or checks. Inclusion of control plots is strongly recommended in all statistically sound experimental field work. Failure to include control plots or the incorporation of inadequate control plots provides only questionable results that are unacceptable for publication and sales promotion. Check plot selection should be made with the same objectivity as that of other plots. The same variables that may affect treatment plots also may affect control plots. Thus, the location of control plots within a field should not be selected arbitrarily. Likewise, control animals should not be arbitrarily selected but should represent a random sample of the test population.

On-farm research

A well-thought-out on-farm experiment can complement research conducted on a research station. However, the research station is usually a more appropriate place to screen riskier alternatives, experiments that may make a field look bad, or experiments that could leave producers with a lingering problem, such as weeds.

Acceptance of an on-farm research project will be enhanced if its purpose is clearly identified, so that it is judged by appropriate standards. In particular, the distinction between demonstration and research must be kept clear.

The researcher may decide to conduct an experiment on-farm if the experiment itself requires a private farm and operator, or the farm location offers physical conditions that are not found on-station (e.g., a particular soil type, climate, or pest infestation). Other factors may influence any particular researcher to conduct an experiment on-farm rather than on-station. In many instances, on-farm research is more credible and accessible to producers, particularly if it is done with large, machine-harvested plots. The researcher should keep in mind that the two sites (on-farm vs. on-station) require different intensiveness in monitoring the experimental plots.

It is important to distinguish producers' and researchers' respective responsibilities. It is not fair to expect extra work from producers or meticulous station-type data collection during busy seasons. The researchers must adapt the experiment to what they judge each producer can conveniently do. Decisions must be made on experimental designs, such as the number of treatments and replications or the size of the plots, to accommodate the constraints of a private farming operation. Producers tend to favor on-farm trials that use standard machinery and require little extra time to implement and maintain. One on-farm method that has become acceptable to a large number of producers makes use of long, narrow strip plots. The plots are arranged in randomized blocks to accommodate large machinery. All strips are managed identically throughout the growing season except for the treatments being tested. For example, if a trial is testing different methods of weed control, all strips should receive the same primary tillage, seedbed preparation, fertilizer application, insect control, and so on. The only difference in management over the entire test area in this trial would be the weed control treatment used on individual strip plots.

Once a cooperator has been selected, efforts should be made to compensate him or her fairly for time and effort in a manner appropriate to each individual situation.

Experimental design

Designing an experiment is an extremely important process because errors made in the design can invalidate the results of the entire experiment. The most able statistician cannot validate conclusions from an improperly designed experiment. It is generally best to avoid experiments or demonstrations that involve elaborate designs. Knowing your financial, land-area and field-resource limits can help in planning a successful experiment. If you have questions about your experimental design or method, seek assistance from a qualified statistician before starting your research. The following are descriptions of several commonly used field experimental designs.

Completely randomized. The completely randomized design is the simplest design (Figure 1). It is set up by assigning treatments and controls at random to a previously determined set of experimental units. Any number of treatments may be tested in this design. It is desirable to assign the same number of experimental units to each treatment and control, but it is not essential.

When plots are laid out within a field, the number of plots is determined by multiplying the combined number of treatments and controls by the number of replications desired. In Figure 1, for example, 3 herbicides + 1 control = 4 treatments x 3 replications = 12 plots. The treatments are assigned to the plots at random.

The advantages of the completely randomized

A	B	D	D	C	D
B	C	C	B	A	A

Figure 1. Completely randomized design with three replications, three herbicide treatments (A, B, and C), and one

design are that it is flexible and simple. However, estimating experimental error with this design may be less precise than with other designs. The completely randomized design is not usually the most efficient design for research in field crops and may be more appropriate for trials with livestock.

Randomized complete block. The randomized complete block design (Figure 2) is used to account for natural variability that would otherwise obscure treatment differences. In this design, the treatments are assigned at random to a group of plots called a block; thus, a block is a grouping of single occurrences of each treatment. Because adjacent plots are more likely to produce similar yields or have similar pest infestations or similar fertility than those separated by some distance, the block is kept as compact as possible. This is accomplished by placing the plots, usually long and narrow, close together. The number of treatments also should be as small as possible. Note that each treatment occurs only once in each of the four blocks. Treatments are assigned at random to plots within each block, with a separate randomization made for each block. Crop rows should run perpendicular to the fertility gradient to minimize experimental error.

1	2	3	4
D	A	C	C
A	D	D	B
B	C	B	D
C	B	A	A

Low fertility → → → → High fertility

Figure 2. Randomized complete block design replicated four times with three herbicide treatments (A, B and C) and one untreated control (D).

Split-plot. The split plot design is useful with factorial experiments that evaluate both pesticide performance and crop management practices (e.g., tillage, row spacing, crop variety). An example would be an experiment to evaluate the effectiveness of three herbicide treatments in no-till and conventional tillage (Figure 3). To simplify the experiment, tillage treatments are established as whole plots. Each whole plot is divided into four subplots and the herbicide treatments (three herbicide treatments plus a control) are randomized within each whole plot. The advantage of this design is that it simplifies establishing experiments where large equipment is used. The

Rep. 1		Rep. 2		Rep. 3	
4	2	4	1	2	1
3	1	1	2	3	4
1	4	3	3	1	3
2	3	2	4	4	2
nt	ct	ct	nt	ct	nt

Figure 3. Randomized split-plot design with three replications. No-till (nt) and conventional tillage (ct) treatments are the whole-plot treatments and herbicide treatments (1 - 4) are subplot treatments.

Rep. 1

a	b	c
1→	→	→
2→	→	→
3→	→	→
4→	→	→

Rep. 2

b	c	a
2→	→	→
3→	→	→
4→	→	→
1→	→	→

Rep. 3

c	a	b
4→	→	→
1→	→	→
2→	→	→
3→	→	→

Figure 4. Split-block design with three replications, three main treatments (a, b, c) of corn planting dates, and four subplots (1, 2, 3, 4) of fertilizer treatments. Fertilizer treatments are continued across the main treatments to facilitate application with large equipment. This design differs from the split-plot design in which subplots are randomized within each main treatment.

a	b	c	d
b	a	d	c
c	d	b	a
d	c	a	b

Figure 5. Latin square design with four replications, three herbicide treatments (a, b, c) and a control (d).

disadvantage is a loss in precision in determining differences among the whole-plot treatments.

Split-block. The split-block design is a variation of the split-plot design; subunit treatments are applied in strips across an entire replication of main plot treatments (see Figure 4). This arrangement often facilitates physical operations in the subunits but sacrifices precision in comparing the effects of the subunit treatments.

Latin square. The Latin square design groups treatments in two different ways — by columns as well as rows (Figure 5). Every treatment occurs once in each block (row) and once in each column. Variability across the experimental area is measured and removed in two directions. With the Latin square design, the number of treatments must equal the number of replications. With a large number of treatments this design becomes cumbersome. Usually, this design is used for experiments where there are from four to eight treatments.

Factorial. The factorial design is useful when investigating the effects of each of a number of variables, or factors, on some response. There are advantages to be gained by combining the study of several factors in the same factorial experiment. Factorial experiments are highly efficient because every observation supplies information about all the factors included in the experiment. Also, these types of experiments investigate the relationships between the effects of different factors. The treatments consist of all combinations that can be formed from the different factors. Each treatment combination is randomized within each replication. Such a design is useful when studying the effects of several rates of several pesticides applied in the same experiment (Figure 6).

Rep. 1

a_0b_0	a_0b_1	a_0b_2
a_1b_0	a_1b_1	a_1b_2
a_2b_0	a_2b_1	a_2b_2

Rep. 2

a_0b_1	a_1b_1	a_2b_2
a_0b_0	a_1b_2	a_0b_2
a_2b_1	a_2b_0	a_1b_0

Rep. 3

a_1b_0	a_2b_1	a_1b_2
a_1b_1	a_2b_2	a_2b_0
a_0b_0	a_0b_1	a_0b_2

Figure 6. Factorial design with three replications and two herbicide treatments (a and b) each applied at two rates (1 and 2) with controls (0).

Glossary

Acetolactate synthase-inhibiting. Group of herbicides that inhibit an enzyme that is required in the process of forming several essential plant amino acids.

Acetylcholine. An enzyme that transmits nerve signals between nerves and muscles, sensory organs, or other nerves.

Acute exposure. A single or limited exposure to a pesticide that may result in injury or death.

Adsorptive surface. Area of attachment of pesticide molecules to the surface of a particle of soil or other material.

Amino acids. Basic building blocks of proteins in plants and animals.

Antagonism. Reduced toxicity or effectiveness as a result of combining one pesticide with another.

Antidote. Substance that detoxifies the effects of a particular pesticide.

Biodegradation. The decomposition of pesticide residues in the environment by bacteria and other microorganisms that use the residues as nutrient sources.

Biological magnification. The tendency of certain pesticides to become progressively more concentrated in each type of organism when moving from the bottom to the top organism in a food chain.

Calibration. The process of measuring the output of pesticide application equipment so that the proper amount of pesticide can be applied to a given area.

Chloroacetamide herbicide. Family of herbicides, including acetochlor, alachlor, metolachlor, and propachlor; they are most commonly soil-applied and inhibit emerging roots and shoots.

Chloroplast. Organelles present in large numbers within plant cells that contain protein, lipids and pigments.

Cholinesterase. The enzyme that destroys acetylcholine.

Colloidal fraction. That portion of a soil consisting of clay and organic matter, in which most of the surface reactions take place.

Defoliant. Substance used to remove leaves from target plants, often as an aid in harvesting the plant.

Dithiocarbamate fungicide. Sulfur-containing, broad-spectrum, contact fungicides used in controlling many fungal diseases.

Enzyme. Proteins, formed in plant and animal cells or made synthetically, that act as organic catalysts in initiating or speeding up specific chemical reactions.

Foliar-applied herbicide. A herbicide that is applied to the stem, leaves or needles of a plant.

Fumigant. Liquid or solid chemical that forms a gas that kills organisms.

Fungicide. A pesticide used to prevent, repel, or mitigate fungal infections.

Growth regulator. A hormonal chemical capable of changing the growth of a plant or animal.

Herbicide. A pesticide used to prevent, destroy, or mitigate plants that grow where they are not wanted.

Insecticide. A pesticide used to prevent, destroy, repel, mitigate, or attract insects and their relatives.

Ionization. Process in which a chemical takes on a positive or negative electrical charge due to losing or gaining electrons through a chemical reaction.

Metabolism. The total chemical process that takes place in a living organism to utilize food and manage wastes, provide for growth and reproduction, and accomplish all other life functions.

Metabolite. A product that is produced in a living organism through metabolism.

Mode of action. The mechanism(s) by which pesticides injure or kill pests.

Nematicide. A pesticide used to prevent, repel, destroy, or mitigate the effects of nematodes.

Organic matter. Portion of soil containing carbon and hydrogen.

Organochlorine compound. A class of pesticides, commonly used as insecticides, that contain a chlorine atom incorporated into an organic molecule. Organochlorines are often highly persistent.

Organophosphorous compound. A commonly used class of pesticides containing phosphorous; most break down rapidly in the environment.

Permeability. Referring to a surface or membrane that is porous, allowing certain substances to pass through.

Pesticide. A chemical or mixture of chemicals used to destroy, prevent, repel, or attract any animal, plant, or disease considered a pest.

Photosynthesis. The biological production of organic substances, chiefly sugars, occurring in green plant cells in the presence of light.

Phytotoxicity. An effect that is injurious or lethal to plants.

Postemergence herbicide. A herbicide applied after emergence of the specified weed or crop.

Preemergence herbicide. A herbicide applied to the soil before emergence of the specified weed or crop.

Protoplasm. The living portion of the cell.

Resistance. Genetic qualities of a pest population that enable individuals to resist the effects of certain types of pesticides that are toxic to other members of that species.

Restricted-use pesticide. A pesticide that can only be sold to, or applied by, individuals who are licensed as commercial or private applicators or persons under their direct supervision.

Selective herbicide. A chemical that is more toxic to some plant species than to others.

Selectivity. The ability of a pesticide to kill some pests but not others.

Soil texture. Relative content percentages of clay, sand and silt in any given soil.

Synergism. The action of two pesticides that produces a greater cumulative effect when the pesticides are used together than when they are used individually.

Systemic herbicide. A herbicide that is absorbed by treated plants and translocated to other tissues along with other substances in vascular tissue.

Appendix A
Convenient Conversion Factors

Multiply	By	To get
Acres	0.405	Hectares
Acres	4,047.0	Square meters
Acres	4,840.0	Square yards
Acres	43,560.0	Square feet
Acre-feet	1,233.49	Cubic meters
Acre-feet	325,850.58	Gallons
Bushels	0.0461	Cubic yards
Bushels	1.2437	Cubic feet
Bushels	4.0	Pecks
Bushels	32.0	Quarts (dry)
Bushels	35.24	Liters
Bushels	64.0	Pints (dry)
Bushels	2,150.42	Cubic inches
Centimeters	0.3937	Inches
Centimeters	0.01	Meters
Centimeters	10.0	Millimeters
Cubic centimeters	0.0610	Cubic inches
Cubic centimeters	0.03381	Ounces (liquid)
Cubic centimeters	1.0	Milliliters of water
Cubic centimeters	1.0	Grams of water
Cubic feet	0.028317	Cubic meters
Cubic feet	0.0370	Cubic yards
Cubic feet	0.8040	Bushels
Cubic feet	7.4805	Gallons
Cubic feet	25.71	Quarts (dry)
Cubic feet	28.32	Liters
Cubic feet	29.92	Quarts (liquid)
Cubic feet	51.42	Pints (dry)
Cubic feet	59.84	Pints (liquid)
Cubic feet	62.4	Pounds of water
Cubic feet	1,728.0	Cubic inches
Cubic feet	28,317.0	Cubic centimeters
Cubic inches	0.000016	Cubic meters
Cubic inches	0.0005	Bushels

Multiply	By	To get
Cubic inches	0.0006	Cubic feet
Cubic inches	0.0019	Pecks (dry)
Cubic inches	0.0037	Gallons (dry)
Cubic inches	0.0043	Gallons (liquid)
Cubic inches	0.0149	Quarts (dry)
Cubic inches	0.0164	Liters
Cubic inches	0.0173	Quarts (liquid)
Cubic inches	0.0298	Pints (dry)
Cubic inches	0.0346	Pints (liquid)
Cubic inches	0.0361	Pounds of water
Cubic inches	0.5540	Ounces (liquid)
Cubic inches	16.3871	Cubic centimeters
Cubic meters	1.308	Cubic yards
Cubic meters	35.31	Cubic feet
Cubic meters	264.2	Gallons
Cubic meters	1,000.0	Liters
Cubic meters	1,057.0	Quarts (liquid)
Cubic meters	2,113.0	Pints (liquid)
Cubic meters	61,023.0	Cubic inches
Cubic meters	1,000,000.0	Cubic centimeters
Cubic yards	0.7646	Cubic meters
Cubic yards	21.71	Bushels
Cubic yards	27.0	Cubic feet
Cubic yards	202.0	Gallons (liquid)
Cubic yards	807.9	Quarts (liquid)
Cubic yards	1,616.0	Pints (liquid)
Cubic yards	7,646.0	Liters
Cubic yards	46,656.0	Cubic inches
Cups	0.25	Quarts (liquid)
Cups	0.5	Pints (liquid)
Cups	8.0	Ounces (liquid)
Cups	16.0	Tablespoons
Cups	48.0	Teaspoons
Cups	236.5	Milliliters

Multiply	By	To get
Feet	0.3048	Meters
Feet	0.3333	Yards
Feet	12.0	Inches
Feet	30.48	Centimeters
Feet per minute	0.01136	Miles per hour
Feet per minute	0.01667	Feet per second
Feet per minute	0.01829	Kilometers per hour
Feet per minute	0.3048	Meters per minute
Feet per minute	0.3333	Yards per minute
Feet per minute	60.0	Feet per hour
Gallons	0.00378	Cubic meters
Gallons	0.1337	Cubic feet
Gallons	3.785	Liters
Gallons	4.0	Quarts (liquid)
Gallons	8.0	Pints (liquid)
Gallons	8.337	Pounds
Gallons	128.0	Ounces (liquid)
Gallons	231.0	Cubic inches (liquid)
Gallons	269.0	Cubic inches (dry)
Gallons	3,785.0	Cubic centimeters
Gallons of water	0.0038	Cubic meters
Gallons of water	0.0049	Cubic yards
Gallons of water	0.1337	Cubic feet
Gallons of water	3.7853	Kilograms
Gallons of water	8.3453	Pounds of water
Gallons of water	3,785.3446	Grams
Grains	0.0648	Grams
Grams	0.001	Kilograms
Grams	0.0022	Pounds
Grams	0.0353	Ounces
Grams	15.43	Grains
Grams	1,000.0	Milligrams
Grams per liter	10.0	Percent
Grams per liter	1,000.0	Parts per million
Hectares	2.47	Acres
Hectares	10,000.0	Square meters

Multiply	By	To get
Hectares	11,954.8	Square yards
Hectares	107,593.2	Square feet
Inches	0.0254	Meters
Inches	0.02778	Yards
Inches	0.08333	Feet
Inches	2.54	Centimeters
Kilograms	0.0011	Tons
Kilograms	2.205	Pounds
Kilograms	35.28	Ounces
Kilograms	1,000.0	Grams
Kilometers	0.6214	Miles
Kilometers	1,000.0	Meters
Kilometers	1,093.611	Yards
Kilometers	3,280.833	Feet
Kilometers per hour	0.6214	Miles per hour
Kilometers per hour	16.6667	Meters per minute
Kilometers per hour	18.2268	Yards per minute
Kilometers per hour	54.6806	Feet per minute
Liters	0.001	Cubic meters
Liters	0.0353	Cubic feet
Liters	0.2642	Gallons (liquid)
Liters	1.0	Kilograms of water
Liters	1.057	Quarts (liquid)
Liters	2.113	Pints (liquid)
Liters	33.8143	Ounces
Liters	61.02	Cubic inches
Liters	1,000.0	Cubic centimeters
Liters	1,000.0	Grams of water
Meters	0.001	Kilometers
Meters	1.094	Yards
Meters	3.281	Feet
Meters	39.37	Inches
Meters	100.0	Centimeters
Meters	1,000.0	Millimeters
Metric tons	1.1	Tons (U.S.)
Metric tons	1,000.0	Kilograms

Multiply	By	To get
Metric tons	2,204.6	Pounds
Metric tons	1,000,000.0	Grams
Miles	1.6093	Kilometers
Miles	1,609.3	Meters
Miles	26.8217	Meters per minute
Miles	29.3333	Yards per minute
Miles	5,280.0	Feet
Miles per hour	1.467	Feet per second
Miles per hour	1.6093	Kilometers per hour
Miles per hour	26.8217	Meters per minute
Miles per hour	29.3333	Yards per minute
Miles per hour	88.0	Feet per minute
Miles per minute	26.82	Meters per second
Miles per minute	29.333	Yards per second
Miles per minute	88.0	Feet per second
Milliliters	0.00105	Quarts (liquid)
Milliliters	0.0021	Pints (liquid)
Milliliters	0.0042	Cups (liquid)
Milliliters	0.0338	Ounces (liquid)
Milliliters	0.0676	Tablespoons
Milliliters	0.2029	Teaspoons
Milliliters	1.0	Cubic centimeters of water
Milliliters	1.0	Grams of water
Ounces (liquid)	0.00781	Gallons
Ounces (liquid)	0.03125	Quarts (liquid)
Ounces (liquid)	0.0625	Pints (liquid)
Ounces (dry)	0.0625	Pounds
Ounces (liquid)	0.125	Cups (liquid)
Ounces (liquid)	1.805	Cubic inches
Ounces (liquid)	2.0	Tablespoons
Ounces (liquid)	6.0	Teaspoons
Ounces (dry)	28.3495	Grams
Ounces (liquid)	29.573	Milliliters
Ounces (dry)	437.5	Grains
Parts per million	0.0001	Percent
Parts per million	0.001	Liters/cubic meter

Multiply	By	To get
Parts per million	0.001	Grams per liter
Parts per million	0.001	Milliliters per liter
Parts per million	0.013	Ounces per 100 gallons of water
Parts per million	0.0584	Grains per U.S. gallon
Parts per million	0.3295	Gallons per acre-foot of water
Parts per million	1.0	Milligrams per liter
Parts per million	1.0	Milligrams per kilogram
Parts per million	1.0	Milliliters per cubic meter
Parts per million	2.7181	Pounds per acre-foot of water
Parts per million	8.345	Pounds per million gallons of water
Pecks	0.25	Bushels
Pecks	8.0	Quarts (dry)
Pecks	16.0	Pints (dry)
Pecks	537.605	Cubic inches
Percent	1.33	Ounces (dry) per gallon of water
Percent	8.34	Pounds per 100 gallons of water
Percent	10.00	Grams per kilogram
Percent	10.00	Grams per liter
Percent	10,000.00	Parts per million
Percent	10.00	Grams per kilogram
Percent	10.00	Grams per liter
Percent	10,000.00	Parts per million
Pints (dry)	0.0156	Bushels
Pints (dry)	0.0625	Pecks
Pints (liquid)	0.125	Gallons
Pints (liquid)	0.4732	Liters
Pints (liquid)	0.5	Quarts (liquid)
Pints (liquid)	0.5	Quarts (dry)
Pints (liquid)	2.0	Cups
Pints (liquid)	16.0	Ounces (liquid)
Pints (liquid)	28.875	Cubic inches (liquid)

Multiply	By	To get
Pints (dry)	33.6003	Cubic inches (dry)
Pounds	0.0005	Tons
Pounds	0.4536	Kilograms
Pounds	16.0	Ounces
Pounds	453.5924	Grams
Pounds	7,000.0	Grains
Pounds of water	0.0160	Cubic feet
Pounds of water	0.1198	Gallons
Pounds of water	0.4536	Liters
Pounds of water	27.693	Cubic inches
Quarts (liquid)	0.00094	Cubic meters
Quarts (liquid)	0.0012	Cubic yards
Quarts (dry)	0.03125	Bushels
Quarts (liquid)	0.0334	Cubic feet (liquid)
Quarts (dry)	0.0389	Cubic feet (dry)
Quarts (dry)	0.125	Pecks
Quarts (liquid)	0.25	Gallons (liquid)
Quarts (liquid)	0.9463	Liters
Quarts (liquid)	2.0	Pints (liquid)
Quarts (dry)	2.0	Pints (dry)
Quarts (liquid)	2.0868	Pounds of water
Quarts (liquid)	4.0	Cups
Quarts (liquid)	32.0	Ounces (liquid)
Quarts (liquid)	57.75	Cubic inches (liquid)
Quarts (dry)	67.20	Cubic inches (dry)
Square feet	0.000009	Hectares
Square feet	0.000023	Acres
Square feet	0.0929	Square meters
Square feet	0.1111	Square yards
Square feet	144.0	Square inches
Square inches	0.00064	Square meters
Square inches	0.00077	Square yards
Square inches	0.00694	Square feet
Square kilometers	0.3861	Square miles
Square kilometers	100.0	Hectares

Multiply	By	To get
Square kilometers	247.104	Acres
Square kilometers	1,000,000.0	Square meters
Square kilometers	1,195,982.7	Square yards
Square kilometers	10,763,865.0	Square feet
Square meters	0.0001	Hectares
Square meters	1.308	Square yards
Square meters	10.765	Square yards
Square meters	1,549.9669	Square feet
Square miles	2.5899	Square kilometers
Square miles	258.99	Hectares
Square miles	640.0	Acres
Square miles	2,589,735.5	Square meters
Square miles	3,097,600.0	Square yards
Square miles	27,878,400.0	Square feet
Square yards	0.00008	Hectares
Square yards	0.00021	Acres
Square yards	0.8361	Square meters
Square yards	9.0	Square feet
Square yards	1,296.0	Square inches
Tablespoons	0.0625	Cups
Tablespoons	0.5	Ounces
Tablespoons	3.0	Teaspoons
Tablespoons	15.0	Milliliters
Teaspoons	0.0208	Cups
Teaspoons	0.1667	Ounces
Teaspoons	0.3333	Tablespoons
Teaspoons	5.0	Milliliters
Tons	0.907	Metric tons
Tons	907.1849	Kilograms
Tons	2,000.0	Pounds
Tons	32,000.0	Ounces
Yards	0.000568	Miles
Yards	0.9144	Meters
Yards	3.0	Feet
Yards	36.0	Inches

Appendix B

University of Missouri plant and soil diagnostic services

Extension Plant Disease Clinic
(573) 882-3019

There is no charge for most samples submitted to the Extension Plant Disease Clinic. The exceptions are turf samples and some virus testing.

Insect Identification
(573) 882-3019

There is no charge for insects submitted for identification.

Weed/Plant Identification
(573) 882-3019

There is a $10/sample charge for weeds or plant material submitted for identification.

Veterinary Medical Diagnostic Laboratory — Toxicology
(573) 882-6811

Mycotoxins and other toxins

Analysis	Description of test
Mycotoxin screen	Analysis for aflatoxins, ochratoxin A, T-2 toxin, DAS, vomitoxin, citrinin, sterigmatocystin, and zearalenone
Fumonisin B_1	Screens corn for this toxin produced by *Fusarium moniliforme*
Ergot analysis	Screen for the presence of *Claviceps purpurea* or ergot contamination of cereal grains and ground and pelleted feed
Ergovaline analysis	Fescue seed or forage, seasonal, only available when research samples are being processed
Nitrate analysis	
Cyanide analysis	

NOTE: Please inquire for current service prices.

Experiment Station Chemical Laboratories
(573) 882-2608

The Experiment Station Chemical Laboratories offer a wide range of analytical services that include official methods of analysis of foods, feeds, plants, drinking water, wastewater, limestone, pesticide screening, and solid and liquid fertilizers.

Environmental analyses. Drinking water and wastewater discharges: A large range of EPA methods for measuring the concentration of many organic compounds and pesticides in drinking water (EPA 500 series) and in industrial and municipal wastewater discharges (EPA 600 series) are available at the Experiment Station Chemical Laboratories. Complete ion analyses are also available. Please inquire.

Fertilizers and limestone. The Experiment Station Chemical Laboratories perform a regulatory function for the state of Missouri by using techniques approved by the Association of Official Analytical Chemists to analyze fertilizer and limestone samples submitted to the laboratory by official inspectors. These same AOAC analytical methods are also available to individuals submitting unofficial fertilizer and limestone samples to the laboratory to test for their fertilizer or limestone value, to test water for fertilizer content or contamination, to test required secondary containment areas for fertilizer contamination, etc. Please inquire.

Nutritional analyses. Various tests are available for amino acids, fats, fibers, proteins, cholesterol, carbohydrates, minerals, vitamins, etc. Please inquire.

Soil and Plant Testing Services
(573) 882-0623 (Columbia)
(573) 379-5431 (Portageville)

Available soil fertility tests:

1. Regular test (includes salt pH [pHs], neutralizable acidity, organic matter, Bray-1 phosphorous, potassium, calcium, and magnesium)
2. Zinc
3. Sulfur
4. Iron, manganese and copper
5. Sodium
6. Boron
7. Nitrate
8. Water pH (pH_w) or pH_s
9. Electrical conductivity
10. Particle size analysis
11. Lime requirement

Other services include water analysis, plant analysis and growing media analysis. Please inquire for current service prices, sample boxes, mailing cartons, and sample information forms.

Extension Plant Nematology Laboratory
(573) 882-2716

Tests available:

1. *Pratylenchus* or *Meloidogyne* species identification
2. Soybean cyst egg count
3. Soybean cyst nematode race determination
4. Plant parasitic nematode identification (other than soybean cyst nematode)

Please inquire for current service prices, packing and mailing samples, and sample submission forms.

Appendix C

Extension references

The following selected references regarding pests and pesticides related to Missouri conditions are available from University of Missouri Extension Publications by calling 1-800-292-0969.

Corn:

G4153	Corn Stunting Virus Diseases in Missouri
M160	Insect and Disease Management: Field Crops, Forages and Livestock
M166	Corn Insect Pests: A Diagnostic Guide
MP517	A Pictorial Field Key to Wireworms Attacking Corn in the Midwest
MP540	Review of Weed Competition in Soybeans and Corn
MP575	Weed Control Guide for Missouri Field Crops
PS004	Corn Insects - Above Ground
PS005	Corn Insects - Below Ground
PS150	Corn Herbicide Injury I
RP327	European Corn Borer Ecology and Management

Cotton:

G4251	Cotton Weed Control
G4252	Cotton Insect Control
G4253	Cotton Harvest Aids
G4254	Cotton Seedling Diseases: Answers to Frequently Asked Questions
G4255	The Boll Weevil in Missouri: History, Biology and Management
G4258	Plant Growth Regulators for Cotton
G4259	Cotton Nematodes in Missouri: Your Hidden Enemies
G4261	Cotton Disease and Nematode Management
M160	Insect and Disease Management: Field Crops, Forages and Livestock
MP575	Weed Control Guide for Missouri Field Crops
PS0012	Cotton Insects and Mites

Forages:

G4551	Alfalfa Diseases in Missouri
G4558	Sclerotinia Crown and Stem Rot of Alfalfa
G4563	Grasshopper Control in Missouri Forage Crops and Pastures
G4569	Blister Beetle Management in Alfalfa
M139	Detecting, Identifying and Managing Alfalfa Pests in Missouri
M160	Insect and Disease Management: Field Crops, Forages and Livestock
MP581	Weed and Brush Control Guide for Forages, Pastures and Non-Cropland in Missouri
MX340	Clover Diseases I
MX341	Clover Diseases II
PS008	Common Forage Legume Insects

Rice:

G4362	Controlling Insects in Rice
M160	Insect and Disease Management: Field Crops, Forages and Livestock
MP575	Weed Control Guide for Missouri Field Crops
MP645	Rice Blast: Identification and Control
MP646	Rice Sheath Blight Control

Small Grains:

G4317	Scab of Wheat
G4318	Virus Diseases of Wheat
G4319	Wheat Diseases in Missouri
G4320	Foliar Fungicides for Wheat
G4345	Wheat Take-All
M160	Insect and Disease Management: Field Crops, Forages and Livestock
MP575	Weed Control Guide for Missouri Field Crops
PS007	Common Small Grain Insects

Sorghum:

G4349	Sorghum Aphid Pest Management
G4354	Controlling Diseases of Grain Sorghum
G4356	Management of Grain Sorghum Diseases in Missouri
M160	Insect and Disease Management: Field Crops, Forages and Livestock
MP575	Weed Control Guide for Missouri Field Crops

Soybeans:

G4441	Seed Treatment Fungicides for Soybeans
G4448	Controlling Rodent Damage in No-Till Corn and Soybeans
G4450	Soybean Cyst Nematode
G4452	Soybean Disease Management
G4470	Soybean Harvest Aids
M160	Insect and Disease Management: Field Crops, Forages and Livestock
MP540	Review of Weed Competition in Soybeans and Corn
MP575	Weed Control Guide for Missouri Field Crops
MP686	Using Reduced Herbicides Rates for Weed Control in Soybeans
PS0006	Common Soybean Insects

Pesticides:

G1270	Calibrating Field Sprayers
G1272	Spray Mix Calculations
G1273	Calibrating Granular Pesticide Applicators
G1915	First Aid for Pesticide Poisoning

G1916 Pesticide Application Safety
G4852 Cleaning Field Sprayers to Avoid Crop Injury
G7510 Pesticide Dilution Table
G7520 Pesticides and the Environment
G7550 Missouri Restricted-Use Pesticide List
M88 Right-of-Way Pest Control
M89 Ornamental and Turf Pest Control
M90 Agricultural Animal Pest Control
M91 Demonstration and Research Pest Control
M92 Seed Treatment Pest Control
M93 Agricultural Plant Pest Control
M94 Forest Pest Control
M95 General Structural Pest Control
M96 Termite Pest Control
M97 Fumigation Pest Control
M98 Public Health Pest Control
M99 Aquatic Pest Control
M100 Pesticide Dealers Manual
M101 Wood Products Pest Control
M156 Missouri Turfgrass Pesticide Selection Guide for Professional Applicators
M160 Insect and Disease Management:Field Crops, Forages and Livestock
M161 Insect and Disease Management: Horticultural Crops and Structures
MP575 Weed Control Guide for Missouri Field Crops
MP651 Missouri Commercial Fruit Tree Spray Guide
MX328 Applying Pesticides Correctly: Missouri Core Manual

Weeds:

EV11 Weed Seedling Identification (video)
G4251 Cotton Weed Control
G4856 Aquatic Weed Control in Missouri
G4871 Waterhemp Management in Missouri
G4872 Johnsongrass Control
G4875 Control of Perennial Broadleaf Weeds in Missouri Field Crops
G4907 Herbicide Resistance in Weeds
MP540 Review of Weed Competition in Soybeans and Corn
MP575 Weed Control Guide for Missouri Field Crops
MP581 Weed and Brush Control Guide for Forages, Pastures and Non-Cropland in Missouri
MP686 Using Reduced Herbicides Rates for Weed Control in Soybeans
RP33 Vine Weeds of the North Central States
RP185 Comprehensive Guide to Tolerance and Susceptibility of Weeds and Crops to Herbicides
RP281 Weeds of the North Central States

Emergency Telephone Numbers

Missouri Regional Poison Control Center 1-800-366-8888

For pesticide poisoning emergencies, the Missouri Poison Control Center is accessible through a toll-free number. The center is located and administered by Cardinal Glennon Memorial Hospital in St. Louis. It is staffed 24 hours daily with medical professionals. The center is equipped to refer poisoning accident victims to a local poison control emergency facility.

Missouri Emergency Response Team (573) 634-2436

For pesticide spill emergencies, the Emergency Response Team handles pesticide spills anywhere in Missouri. For information, call (573) 751-7929. Contact: Environmental Emergency Response Coordinator, Missouri Department of Natural Resources, Division of Environmental Quality, P.O. Box 176, Jefferson City, MO 65102.

National Pesticide Safety Team Network (Chemtrec) 1-800-424-9300

The National Agricultural Chemicals Association has a telephone network. This network can tell the applicator the correct contamination procedures to use to send a local safety team to clean up the spill. An applicator can call the network toll free at any time.

National Pesticide Tele-Communications Network 1-800-858-PEST

Call the NPTN network toll free.

U.S. Environmental Protection Agency (EPA) (913) 551-7000

All major pesticide spills must by law be reported immediately to the U.S. Environmental Protection Agency, Region VII Office, 726 Minnesota Avenue, Kansas City, KS 66101. The following information should be reported:

1. *Name, address, and telephone number of person reporting*
2. *Exact location of spill*
3. *Name of company involved and location*
4. *Specific pesticide spilled*
5. *Estimated quantity of pesticide spilled*
6. *Source of spill*
7. *Cause of spill*
8. *Name of body of water involved, or nearest body of water to the spill area*
9. *Action taken for containment and cleanup*

OUTREACH & EXTENSION
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