E. Pest Management

1. How to Improve Pest Management

1.1 Recommendations for More Effective Pest Control

Failure to control a weed, insect, or disease is often blamed on the pesticide when frequently the cause is one of the following: 1. Delaying applications until pests become too large or too numerous, 2. Making applications with insufficient gallonage or with clogged or poorly arranged nozzles, and 3. Selecting the wrong pesticide.

For more effective pest control check the following recommendations:

1. Field Inspection

Keep abreast of the pest situation and buildup in your fields. Frequent examinations (at least twice per week) help determine the proper timing of the next application. Do not apply controls simply because your neighbor does.

2. Integrated Pest Management (IPM)

Guidelines and information about current pest activity in vegetables are published in weekly IPM newsletters and reports. These publications provide accurate information for the timing of pesticide applications and suggestions for more effective control. To receive these newsletters and reports, contact your state Extension IPM specialist or Extension agent, or subscribe online at: *http://plant-pest-advisory.rutgers.edu/*.

Pest control programs use prevention, biological, physical, cultural, and chemical methods in an integrated approach. Field scouts collect pest population data. **Use this up-to-date information to decide whether pesticide applications or other management actions are needed**. Action thresholds for insects are generally expressed as a count of a given life stage or as a damage level based on a recommended sampling procedure. They are intended to reflect the population size that will cause economic damage and warrants the cost of treatment. Thresholds are listed for a number crops and pests in chapter F. **Control decisions are also based on the following: a)** economic action threshold level **-** when the cost of control equals or exceeds potential crop losses attributed to real or potential damage, **b)** field history, **c)** growth stage and vigor of crop, **d)** life stage of the pest, **e)** parasite and predator populations, **f)** pest populations, **g)** resistance to chemicals, **h)** time of the year, **i)** variety, and **j)** weather conditions

To employ an IPM program successfully, basic practices need to be followed. Whether participating in an IPM program, hiring a private consultant, or performing the work yourself, the grower should: **a)** examine fields frequently to determine pest populations and buildup, **b)** apply a control measure only when the economic action threshold level has been reached, and **c)** choose a pesticide that is least harmful to parasites and predators.

3. Resistance Management

Resistance to pesticides develops because pest organisms have genetic resistance to a pesticide and intensive use of that pesticide kills the susceptible individuals in a population, leaving only resistant ones to reproduce. Consult the following sections for more information on how to reduce the risk of developing resistance: E 2.5 for herbicides, E 3.2 for insecticides, and E 4.1 for fungicides.

4. Pest Control: Insect and Weed Population Sampling Techniques and Disease Monitoring

Insect Population Sampling Techniques:

a) Shake cloth (ground cloth): Use a standard 3x3 ft shake cloth to assess insect populations. Randomly choose a site without disturbing the plants and carefully unroll the cloth between two rows. Bend the plants over the cloth one row at a time and beat the plants vigorously. Plants are pushed back to their original position and gently shaken to dislodge insects held on stems, leaves, and branches. Count only insects that have landed on the cloth. The number of sampling sites per field will vary with the crop. **b) Sweep net:** Use a standard 15 inch diameter sweep net to assess insect populations. While walking along one row, swing the net from side to side with a pendulum-like motion. The net should be rotated 180 degrees after each sweep and swung through the foliage in the opposite direction. Each pass of the net is counted as one sweep. The number of sweeps per field will vary with the crop. **c) Visual observation:** Examine plants or plant parts (leaves, stems, flowers) for direct counts of insect stages (eggs, larvae, adults), or for the presence of expected injuries. Counts can be taken on individual plants or a prescribed length of row depending on the crop. Quick moving insects are usually counted before less mobile ones.

Weed Population Sampling Techniques:

a) Weed identification: Weed identification is critical for determining a plant's life-cycle, emergence patterns, and growth; and in turn, are key for developing a successful weed control program. There are excellent on-line weed guides as well as weed identification books. **b) Growth stage determination:** The ability of weeds to compete with the crop is related to weed and crop size. Weed control by herbicides or mechanical methods is also dependent on weed size. Weed control decisions must be carried out before the crop is affected and before the weed is too large to be controlled. **c) Weed population:** Weed competition for light, water, nutrients, and space is dependent on population and is usually expressed as weeds per feet of row or weeds per square meter. Control measures are needed when the weed population exceeds the maximum tolerable population of that species. Problematic weeds and species prone to developing resistance should be controlled before they produce viable seeds.

Disease Monitoring:

a) Determining the crop growth stage: Disease control is primarily obtained by applying protective fungicides on a regular schedule. For many diseases, fungicide application must begin at a certain growth stage and be repeated every 7 to 10 days and according to label instructions. If environmental conditions are favorable for disease development, delaying a spray program will result in a lack of control if the disease has progressed too far. **b) Observing symptoms on plants:** For diseases that do not spread rapidly, fields should be scouted regularly. When the first disease symptoms are noticed, a fungicide should be applied and repeated every 7 to 10 days and according to label instructions. **c) Daily collection of weather conditions in the field:** Predictive systems are available for a few diseases. Temperature, rainfall, relative humidity, and duration of leaf wetness are monitored, and the timing of fungicide application is determined by applying a mathematical model.

5. Weather Conditions

Consider weather conditions before applying a pesticide. Spray only when wind velocity is less than 10 mph. Dust only when it is perfectly calm. Do not spray plants that are showing signs of moisture stress. Certain pesticides, including biological insecticides and some herbicides, are less ineffective in cool weather. Others do not perform well or may cause crop injury when hot or humid conditions occur. If possible, make applications when good weather conditions prevail.

Rainfall or overhead irrigation can wash pesticide deposits from foliage. Wait at least 48 hours after insecticide or systemic fungicide application and allow contact fungicides to dry on the leaf surface before irrigating. More frequent fungicide applications may be needed during and after periods of heavy rainfall. Provide a minimum rain/irrigation-free period of 1 to 4 hours after most postemergence herbicide applications.

Refer to individual product labels for all application precautions or restrictions.

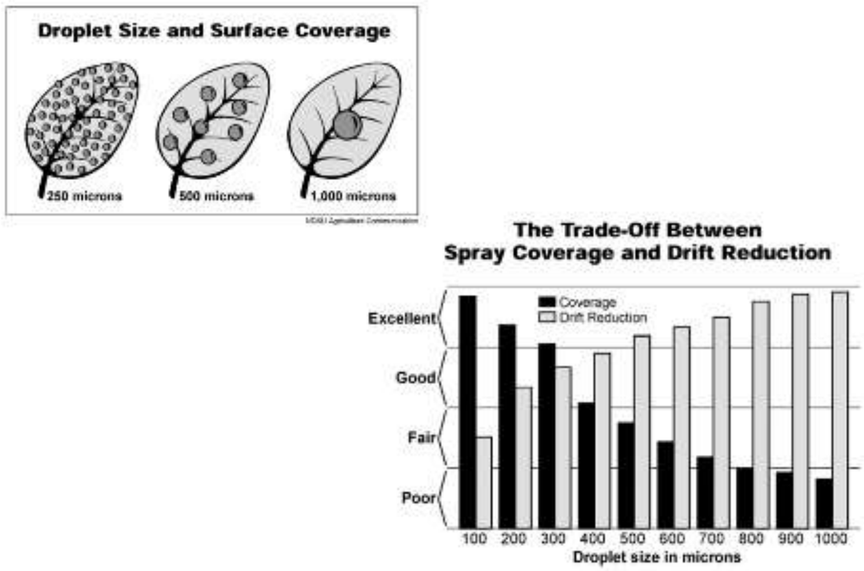
6. Pesticide Coverage of Plants

Non-systemic pesticides require more thorough spray droplet coverage than systemic pesticides which move through the plant's vascular system. A number of insects (*e.g.,* aphids, mites) and diseases also require thorough spray coverage to obtain adequate control. Better pesticide performance can be accomplished by using adequate spray pressure and appropriately designed nozzles and nozzle arrangements with directed sprays to the surface as well as the underside of leaves.

High gallonage, air assisted sprayers and smaller droplets enhance spray coverage of many fungicides and insecticides (Fig. E-1). The volume of water required for adequate spray coverage increases as plants grow and leaf surface area increases; a minimum of 60 gal/A is recommended on vegetable crops for effective pest control with smaller droplets. As a rule of thumb: spray volumes in excess of 100 gal/A would be considered high-volume applications and spray pressures above 60 psi up to 400 psi would be considered high-pressure applications. **Refer to pesticide labels for specific application instructions. Note that pesticide drift increases with smaller spray droplets** (Fig. E-1). More information is available *at: http://sustainable-farming.rutgers.edu/companion-handouts-for-the-backpack-sprayer-videos/.*

Use one sprayer for herbicides and a different sprayer for fungicides and insecticides. Herbicide sprays should be applied at 15-25 gal/A of spray solution using low pressure (30-45 psi), and a nozzle designed to deliver the appropriate size droplet. Never apply herbicides with a high-pressure sprayer suitable for insecticide or fungicide application because excessive **drift** can result in damage to crops and non-target plants in adjacent areas. On crops that are difficult to wet (*e.g*., asparagus, cole crops, onions, peppers, and spinach), disease control can be improved with the addition of a spray adjuvant. However, **do not add oil concentrates, surfactants, spreader-stickers, or any other additive unless specified on the label, or the risk of crop injury may be increased.**

Fig. E-1. Droplet size and surface coverage, and trade-off between spray coverage and drift reduction (North Dakota State University).



7. Pesticide Selection

Know the pests to be controlled and choose the recommended pesticide and rate of application (**check the label**). If in doubt, consult your Extension agent. The herbicide choice should be based on weed species or cropping systems; see Table E-2 for a listing of herbicide effectiveness on common weeds in vegetables.

For insects that are extremely difficult to control or for whom resistance is a risk, it is important to alternate labeled insecticides with different modes of action (MoA). In this guide, recommended insecticides are listed with their Insecticide Resistance Action Committee (IRAC) group number. Insecticides are placed in IRAC groups based on common MoA and alternating between insecticides in different IRAC groups is a way of insuring that different MoA are used on a specific pest. Be alert for a possible aphid or mite buildup following the application of certain insecticides such as synthetic pyrethroids (IRAC 3A). For more assistance, contact your Extension agent.

Caution: Proper application of systemic insecticides is extremely important. Sprays should be directed according to the instructions on the label (which, in general, indicate away from the seed) or crop injury may occur.

Be sure to properly identify disease(s). Many fungicides control only certain diseases and provide no control of others.

8. Pesticide Compatibility

To determine if two pesticides are compatible, use the following "jar test" before tank-mixing pesticides or pesticides and fluid fertilizers:

a. Add 1 pt of water or fertilizer solution to a clean qt jar, add pesticides in the same proportion as used in the field.

b. To a second clean qt jar, add 1 pt of water or fertilizer solution, and add ½ tsp of an adjuvant (such as Compex, Sponto 168D, Uni-Mix, or Unite) to keep the mixture emulsified. After that, add the pesticides to the water-adjuvant or fertilizer solution-adjuvant mixture in the same proportion as used in the field.

c. Close both jars tightly and mix thoroughly by inverting 10 times. Inspect the mixtures immediately and after standing for 30 minutes: If a uniform mix cannot be made, the mixture should not be used. If the mix in either jar remains uniform for 30 minutes, the combination can be used. If the mixture with adjuvant stays mixed and the mixture without adjuvant does not, use the adjuvant in the spray tank. If either mixture separates but readily remixes, constant agitation is required. If nondispersible oil, sludge, or clumps of solids form, do not use the mixture. **Note**. **For compatibility testing, the pesticide can be added directly or premixed in water first. In actual tank-mixing for field application, unless label directions specify otherwise, add pesticides to the water in the tank in this order**: **1)** add, wettable granules or powders; **2)** then add flowables, emulsifiable concentrates, water solubles, and companion surfactants. If tank-mixed adjuvants are used, these should be added first to the fluid carrier in the tank. Thoroughly mix each product before adding the next product.

9. Calibration of Application Equipment

Periodic calibrations of sprayers, dusters, and granule distributors are necessary to ensure accurate delivery rates of pesticides per acre. Calibrations are made by measuring the total gal/A of water applied in the case of sprayers, and the total lb/A of dust or granules in the case of dust and granule distributors. The application of too little spray or dust per acre results in inadequate distribution of toxicant over plant surfaces, usually poor control, and the need for additional applications. Application of too much spray or dust per acre is hazardous for the applicator, is frequently injurious to plants (phytotoxic), and could lead to excessive residues if applied close to harvest.

10. Selection of Sprayer Nozzle Tips

The selection of proper sprayer tips for use with various pesticides is very important. Flat fan-spray tips are designed for preemergence and postemergence application of herbicides. These nozzles produce a tapered-edge spray pattern that overlaps for uniform coverage when properly mounted on a boom. Standard flat fan-spray tips are designed to operate at low pressures (30-60 psi) to produce small- to medium-sized droplets that do not have excessive drift. Some flat fan tips (SP) are designed to operate at even lower pressures (15-40 psi) and are generally used for preemergence herbicide applications. Flat fan nozzle tips are available in brass, plastic, ceramic, stainless steel, and hardened stainless steel. Brass nozzles are inexpensive and are satisfactory for spraying liquid pesticide formulations. Brass nozzles are least durable, and hardened stainless steel nozzles are most durable and are recommended for wettable powder formulations which are more abrasive than liquid formulations. When using any wettable powder, it is essential to calibrate the sprayer frequently because, as a nozzle wears, the volume of spray material delivered through the nozzle increases.

Flood-type nozzle tips are used for various solutions (*e.g.*, complete fertilizer, liquid N) and sometimes for spraying herbicides onto the soil surface prior to incorporation. They are less suited for spraying postemergence herbicides or for applying fungicides or insecticides to plant foliage. Coverage is often less uniform and complete when flood-type nozzles are used, compared with the coverage obtained with other types of nozzles. Results with postemergence herbicides applied with flood-type nozzles may be satisfactory if certain steps are taken to improve target coverage. Space flood-type nozzles a maximum of 20” apart, rather than the standard 40”. This will result in an overlapping spray pattern. Spray at the maximum pressure recommended for the nozzle. These techniques will improve target coverage with flood-type nozzles and result in satisfactory weed control in most cases.

Full and hollow-cone nozzles deliver circular spray patterns and are used for application of insecticides or fungicides to crops where thorough coverage of the leaf surfaces is extremely important and where spray drift will not cause a problem (see step 6). They are used when higher water volumes and spray pressures are recommended. With cone nozzles, the disk size and the number of holes in the whirl plate affect the output rate. Various combinations of disks and whirl plates can be used to achieve the desired spray coverage.

11. Pesticides and pH

Unsatisfactory results of pesticide applications may be caused by poor application, a bad batch of chemical, pest resistance, and weather conditions. Another possible reason may be the incorrect pH of the mixing water. **Check the pH of the water with a pH meter or ask your Extension agent to test a sample.**

Some materials carry a label cautioning the user against mixing the pesticide with alkaline materials, because the pesticide (in particular organophosphate insecticides) undergoes a chemical reaction known as "alkaline hydrolysis" when mixed with alkaline water (*i.e.*, water with a pH greater than 7). The more alkaline the water, the faster the breakdown rate. In addition to lime sulfur, several other materials provide alkaline conditions, *e.g.*, caustic soda, caustic potash, soda ash, magnesia or dolomitic limestone, and liquid ammonia. **Water sources in agricultural areas can vary in pH from below 3 to greater than 10.**

Many manufacturers provide information on the rate at which their products hydrolyze or break down in water solutions. This rate is expressed as "**half-life**," which is the time it takes for 50% hydrolysis or breakdown to occur. Examples of pesticides that are sensitive to hydrolysis in alkaline water solutions include Counter, malathion, dimethoate, Imidan, Lannate, Sevin, and Thimet.

Correction of the alkaline pH: Nutrient buffer sprays are one method; some brand names include: Buffer-X (Kalo Lab), LI-700 Buffer (Hopkins), Mix-Aid (Agway), Nutrient Buffer Sprays (Ortho), Sorba Spray (Leffingwell), Spray-Aide (Miller), and Unite (Hopkins). **Note**: Sprays containing fixed copper fungicides (*e.g.*, Bordeaux mixture, copper oxide, basic copper sulfate, copper hydroxide) should **not** be acidified.

1.2 Calibrating Field Sprayers

Width of Boom The width of boom must be expressed in feet. The boom coverage is equal to the number of nozzles multiplied by the space between two nozzles.

Ground Speed Careful control of ground speed is very important for accurate spray application. Select a gear and throttle setting to maintain constant speed. A speed of 2-3 miles per hour (mph) is desirable. From a "running start," mark off the beginning and end of a 30-second run. The distance traveled (in feet) in this 30-second period divided by 44 will equal the speed in mph. Measure ground speed under field conditions.

Table E-1. Ground Speed Conversion

Tractor speed (mph)	Distance (feet) traveled per minute	Travel time per 500 feet (minutes and seconds)		Tractor speed (mph)	Distance (feet) traveled per minute	Travel time per 500 feet (minutes and seconds)
1.0	88	5 min. and 41 sec		4.5	396	1 min and 16 sec
1.5	132	3 min and 47 sec		5.0	440	1 min and 8 sec
2.0	176	2 min and 50 sec		6.0	528	56 seconds
2.5	220	2 min and 16 sec		7.0	616	49 seconds
3.0	264	1 min and 53 sec		8.0	704	43 seconds
3.5	308	1 min and 37 sec		9.0	792	38 seconds
4.0	352	1 min and 25 sec		10.0	880	34 seconds

Calculating Gallons per Minute Run the sprayer at a certain pressure, and catch the discharge from each nozzle for a known length of time. Collect all the discharge and measure the total volume. Divide this volume by the time in minutes to determine discharge in gallons per minute (GPM). Catching the discharge from each nozzle checks the performance of the individual nozzle. When it is not convenient to catch the discharge from each nozzle, a trough may be used to catch the total discharge. Formula For Calculating Sprayer Gallons Per Acre (GPA):

GPA= 5940 x GPM [per nozzle] / MPH x Width [nozzle spacing in inches]

Before Calibrating

1. Thoroughly clean all nozzles, screens, etc., to ensure proper operation.
2. Check to be sure that all nozzles are the same, are made by one manufacturer, and have the same part number.
3. Check the spray patterns of all nozzles for uniformity. Check the volume of delivery by placing similar containers under each nozzle. All containers should fill at the same rate. Replace nozzles that do not have uniform patterns or do not fill containers at the same rate.
4. Select an operating speed. Note the tachometer reading or mark the throttle setting. When spraying, be sure to use the same speed as used for calibrating.
5. Select an operating pressure. Adjust pressure to desired psi while pump is operating at normal speed and water is actually flowing through the nozzles. This pressure should be the same during calibration and field spraying.

Calibration (Jar Method)

Either a special calibration jar or a homemade one can be used. If you buy one, carefully follow the manufacturer's instructions. Take accurate speed and pressure readings and jar measurements; check several times. Keep in mind that you are collecting less than a quart of liquid to measure an application rate of several gallons per acre for many acres. Any 1-quart or larger container, such as a jar or measuring cup, if calibrated in fluid ounces, can easily be used in the following manner:

1. Measure a course on the same type of surface (*e.g.*, sod, plowed) and same type of terrain (*e.g.*, hilly, level) as that to be sprayed, according to nozzle spacing as follows:

Nozzle spacing (in)	16	20	24	28	32	36	40
Course length (ft)	255	204	170	146	127	113	102

2. Time the seconds it takes the sprayer to cover the measured distance at the desired speed. Average several runs.
3. With the sprayer standing still, operate at selected pressure and pump speed. Catch the water from several nozzles for the number of seconds measured in step 2.
4. Determine the average output per nozzle in fluid ounces. The ounces per nozzle equal the gallons per acre applied by one nozzle per spacing.

Calibration (Boom or Airblast Sprayer)

1. Fill sprayer with water.
2. Spray a measured area (width of area covered x distance traveled) at constant speed and pressure selected from manufacturer's information.
3. Measure amount of water necessary to refill tank (gallons used).
4. Multiply gallons used by 43,560 square feet (sq ft) per acre (A), and divide by the number of square feet in area sprayed. This gives gallons per acre (gal/A).
5. Add correct amount of spray material to tank to give the recommended rate per acre.

Example
Assume: 10 gal of water used to spray an area 660 ft long and 20 ft wide,
Tank size-100 gal, Spray material-2 lb formulated product/A

Calculation: (Gal used x 43,560 sq ft/A) / (area sprayed)
= (10 gal x 43,560 sq ft/A) / (660 ft x 20 ft)
= (435,600 gal x sq ft)/A / 1,320 sq ft
= 33 gal/A (all other units cancel out)
Tank capacity 100 gal / 33 gal/A = 3.03 A/tank

1.3 Calibrating Granular Applicators

Sales of granular fertilizer, herbicides and insecticides for application through granular application equipment have been on the increase. Much of the available equipment was not designed for precision application of granular materials; therefore, extra care must be taken to get the results desired. How well the material is applied is no accident. It will take a conscientious operator, effort, knowledge of equipment, and calibration.

The first step to good application is to be sure the equipment is prepared for operation. Be sure all controls are free and work properly. Check and lubricate moving parts as necessary, remove corrosion, and tighten loose nuts and bolts. Application rates of granular application equipment are affected by several factors: gate openings or settings, ground speed of the applicator, shape and size of granular material, and evenness of the soil surface.

Calibration for Broadcast Applicators (Gravity-Drop or Spinner Applicators)

1. From the label, determine the application rate.
2. From the operators' manual, set dial or feed gate to apply desired rate.
3. On a level surface, fill hopper to a given level and mark this level.
4. Measure test area-length of run will depend on size of equipment. It need not be one long run but can be multiple runs at shorter distances.
5. Apply material to measured area, operating at the speed applicator will travel during application.
6. Weigh amount of material required to refill hopper to the marked level.
7. Determine application rate:

Area covered (A) = number of runs x length of run (ft) x width of application (ft) **/** 43,560 sq ft/A

Application rate (lb/A) = amount applied (lb to refill hopper) **/** area covered (A)

Note. Width of application is width of the spreader for drop or gravity spreaders. For spinner applicators, it is the working width (distance between runs). Check operator's manual for recommendations, generally one-half to three-fourths of overall width spread.

Example:
Assume: Rate: 50 lb/A. Test run: 200 ft. Number of runs: 4. Application width: 12 ft. Lbs to refill hopper: 11.5 lb.

Area covered: (4 runs x 200 ft x 12 ft) / 43,560 sq ft/A = 9,600 runs x sq ft / 43,560 sq ft/A = 0.22 A

Application rate: 11.5 lb / 0.22 A = 52.27 lb/A

8. If application rate is not correct, adjust feed gate opening and recheck.

Calibration for Band Applicators

1. From the label, determine application rate.
2. From the operator’s manual, determine applicator setting and adjust accordingly.
3. Fill hopper half full.
4. Operate applicator until all units are feeding.
5. Stop applicator; remove feed tubes at hopper.
6. Attach paper or plastic bag over hopper openings.
7. Operate applicator over measured distance at the speed equipment will be operated.
8. Weigh and record amount delivered from each hopper.
(Be sure all hoppers and all tubes deliver the same amount.)
9. Calculate application rate:
Area covered in bands (A) = Number of bands x length of run (ft) x band width (ft) / 43,560 sq ft
10. If not correct, readjust and recheck.

Calibration for Changing from Broadcast to Band Application

[Band width (ft) / row spacing (ft)] x broadcast rate (lb/A) = Amount needed (lb/A)

1.4. Pesticide Drift and Misapplication

Serious problems can occur when an unintended pesticide drifts onto your plants, or is directly applied due to misapplication or sprayer contamination. Misapplied herbicides, in particular, can result in significant injury to a vegetable crop for which the herbicide is not labeled. For all pesticides that are misapplied or that drift onto unintended crops, you must make a decision on whether the crop can be sold. To legally sell the produce, there has to be an established tolerance for the particular pesticide(s). Even though a pesticide is not sold for the particular crop, a tolerance may exist. A tolerance is an acceptable level of pesticide allowed based on EPA regulations. If the concentration of the pesticide in your vegetable is above the established tolerance or if there is no tolerance, you have a tainted crop that is illegal to sell. Pesticide residue levels can only be determined by laboratory analysis, contact you state department of agriculture or state extension specialists for an appropriate laboratory. To check for tolerances, go to: *https://www.epa.gov/pesticide-tolerances.*

Tolerances are not the only factor that should be considered in deciding whether or not to sell or consume produce. The U.S. EPA tolerance levels are the best scientific information available, but if your customers have heard of the drift problem, even if residues are below tolerances, selling affected produce may damage your farm's reputation.

Samples for residue analysis must be collected correctly and in a timely manner for it to be useful in the decision-making process. If the harvested part is present, collect that tissue. If fruit are not present, collect samples of recently formed leaves and shoot tips; translocated pesticides will concentrate in those tissues. Ask that fruit samples be collected later to help you in deciding whether or not to sell or consume the fruit. Make sure that samples are collected from the crop plants showing injury and as close as possible to the site of pesticide application.

What will pesticide residue concentrations tell you? Sometimes they may not tell you much. The critical question is: “Are the pesticides absent from the parts you wish to harvest and eat, or are the pesticide concentrations within the tolerances set by the EPA?” But undetectable residues may be due to poor sampling procedure, so care must be taken to ensure the samples were taken from the correct part of the plant, in a timely fashion, and handled properly. Be conservative in how you interpret the residue information.

The scientific literature suggests that acute poisoning effects in humans caused by pesticide residues in vegetables due to drift are very unlikely. Questions about the possible chronic effects (including cancer) from multiple exposures from repeated incidents of pesticide drift along with many other routes of exposure remain the subject of research.

Herbicide drift or herbicides misapplied to a vegetable crop for which the herbicide is not labeled can result in significant visible injury. But, misapplication of any pesticide has the same issues.

1.5 Soil Fumigation

In fields that are infested with soil borne plant pathogens, plant parasitic nematodes, or significant weed populations, soil fumigation can help reduce pest populations. Soil fumigants must be applied properly and a dissipation period between fumigant application and planting of the crop is necessary to prevent plant injury. **Labels should be read carefully before deciding whether to use a soil fumigant.**

Nearly all soil fumigants have been re-registered since 2009 resulting in substantial label changes (see also section D.3.3.1 Soil Fumigants). **Labels now include mandatory stipulations on fumigant application including soil tillage, soil temperature, and soil moisture. Labels have specific requirements for plant-back periods that must be adhered to for crop safety. There are also new personal protective equipment mandates as well as site monitoring and management requirements**. Consult your Extension professional for advice regarding your specific needs and assistance with label interpretation. More information on Nematode Control can be found in the following section.

One of the following multipurpose soil fumigants should be used to provide weed, disease, and/or nematode control. Rates are broadcast rates in product/acre:

- allyl isothiocyanate + chloropicrin (Dominus 67:33), 20 gal/A
- allyl isothiocyanate (Dominus), 10-40 gal/A
- chloropicrin, 25-34 gal/A
- dichloropropene + chloropicrin (Pic-Clor 60) (if available), 20-30 gal/A
- dichloropropene + chloropicrin (Pic-Clor 80), 17-34 gal/A
- dichloropropene + chloropicrin (Telone C-17), 11-17 gal/A
- dichloropropene + chloropicrin (Telone C-35), 13-20.5 gal/A
- dimethyl disulfide + chloropicrin (Paladin) (if available), 50-60 gal/A
- metam-potassium (K-PAM HL), 30-60 gal/A
- metam-sodium (Vapam HL), 37.5-75 gal/A

For nematode control only:

- dichloropropene (Telone II), 9-12 gal/A

To determine if it is safe to plant into fumigated soil, collect a soil sample from the treated field (do not go below the treated depth). Place the sample in a glass jar with a screw top lid. Firmly press numerous seeds of a small seeded vegetable crop (*e.g.*, lettuce or radish) on top of the soil and tighten the lid securely. Repeat the process in another jar with non-fumigated soil to serve as a check. Observe the jars within 1-2 days. If seeds have germinated, it is safe to plant in the field. If seeds have not germinated in the fumigated sample and have germinated in the non-treated sample, then the field is not safe to plant. Rework the field and repeat the process in a few days.

1.6 Nematode Control

Some 100 species of plant-feeding nematodes can seriously damage various crops. Before starting any nematode management procedure, determine what nematodes are present in the soil to find out if action is warranted. If nematode damage is suspected, both soils and roots should be examined to determine if and to what extent nematodes may be involved. Follow the procedures below for proper collection and handling of samples to enable an accurate diagnosis at a Nematode Diagnostic Laboratory.

Soil and Root Samples for Nematode Detection

1. Collecting and Handling

Only a single, composite sample should be collected in each field. If the field is larger than 2 acres, divide the field into 2-acre blocks and collect a composite sample from each block. Label each bag accordingly. This will provide a more accurate assessment of the nematode population and enable more targeted management.

Collect soil and roots from the edges of the affected area(s) in the field. Take a mixture of roots and soil from at least 10 scattered sites, or preferably, under 10 scattered plants in the affected area. Do not take samples from areas where plants are dead. Dig up plants with a shovel and take a small handful of soil and roots from each, or use a soil sampling tube (3/4-inch diameter). Combine the individual samples in a bucket to make a composite sample of at least one quart of soil. Mix the soil in the bucket, then place one pint of the mixed soil in a plastic freezer bag and seal it to prevent drying of the soil. Protect bagged samples from high temperatures and freezing which can kill the nematodes.

Take soil samples while the crop is still growing so that areas that are suspected of being affected by nematodes can be identified and sampled, because these areas may be missed in random sampling. In general, samples can be collected from June through November. However, to plan your cropping sequence, it is best to take these survey samples after harvest in the fall *before* any fall tillage and *before* cold weather arrives. This timing is recommended (and especially important for growers who need to monitor root knot nematode populations) because nematode populations are generally highest in the fall. The chance of detecting damaging levels of plant pathogenic nematodes is greatest at that time. The *worst* time to sample to detect root knot nematodes is in late spring just before planting.

Survey samples should be taken at a depth of 8-10 inches, and several inches from the base of the plants, between plants in the row. Do not take samples if the soil is wet. The moisture level should be less than field capacity and there should not be any free water in the plastic bag after adding the sample. Use a soil sampling tube and take 20 to 25 cores per sample in a random pattern in the field. Mix soil cores in a plastic bucket and immediately place a pint of soil in a plastic bag or a nematode soil sample kit purchased from a Nematode Diagnostic Laboratory.

2. Submitting Samples to a Nematode Diagnostic Laboratory

Samples should be sent to the laboratory as soon as possible after collection. If there is any delay, refrigerate samples until shipment. Provide some insulation around the sample(s) during shipment, such as several layers of newspaper, a padded envelope or Styrofoam peanuts. Mark the samples: "For Nematode Analysis" and include the following information **with each sample** (check with the laboratory to see if any additional information is required):

1. Name and address of the grower and of the person submitting the sample
2. Date collected
3. Name of the present crop, the crop to be planted, and history of the affected area
4. Plant and field symptoms

Attach the paper with this information to the **outside** of the bag of soil. Forward the samples to your Extension agent, or directly to the diagnostic laboratory. There is usually a fee for nematode analyses.

Nematode Management Strategies

Plant-parasitic nematodes are difficult to control after they have become established. The best strategy is to use preventive measures, including nematicides, soil fumigants, and/or cultural practices.

1. Chemical Management of Nematodes

Fumigants

Soil fumigation can effectively control plant-feeding nematodes. See section E 1.5 Soil Fumigation above for specific fumigants, rates, and application techniques.

Non-fumigant nematicides

Several non-fumigant nematicides are currently available for selected vegetable commodities. These nematicides are listed in the sections dealing with the vegetables on which they are labeled. Some non-fumigant nematicides are not labeled in all states within the mid-Atlantic region, so consult the label carefully before applying a chemical. These nematicides do not volatilize in the soil as do fumigants. Consequently, these chemicals are effective over a wider range of soil temperature and moisture than are fumigants.

Chemicals registered for use on selected vegetables include:
Contact nematicides: Counter (20CR), Mocap (10G and 6EC), Nimitz (4EC), Velum Prime.
Both contact and systemic nematicide: Vydate L.
Consult the label before applying any of these chemicals.

Factors Affecting the Efficacy of Nematicides

As with any pesticide, the two factors that determine efficacy are **concentration** and **exposure time**. If toxic nematicide concentrations do not come in contact with nematodes for a sufficient period of time, nematode control will be poor. Many factors can reduce the concentration of nematicide available in the soil and/or effectively shorten the time that nematodes are exposed. Good site preparation is extremely important. The soil should be thoroughly tilled several weeks before application to break up clods and encourage decomposition of plant residues. Nematicides can adsorb to organic matter and thus reduce the amount of compound free in the soil. Soil clods can interfere with nematicide distribution and reduce efficacy.

Fumigant nematicides such as Telone or Vapam volatilize and move through the soil as a gas. The movement of a fumigant through the soil is strongly affected by factors such as temperature, moisture, and soil texture. Fumigants tend to move upwards through the soil and will dissipate quickly unless the surface is sealed after treatment. Follow the label to ensure that you are applying the correct dose for your conditions.

Most non-fumigant nematicides such as Vydate are organophosphate or carbamate pesticides, which are potent cholinesterase inhibitors. Nimitz and Velum Prime are in different chemical classes than those mentioned above and kill nematodes via unknown modes of action. All of these compounds are extremely water-soluble, and their redistribution in the soil depends on water movement. Excessive rain or irrigation creates a risk of diluting the nematicide below the level needed to be effective. However, too little water may prevent the nematicide from being distributed effectively in the root zone. Nimitz has an additional concern of being phytotoxic to plants under cold stress; under those conditions, plants grow much slower than those not treated with Nimitz. During warmer periods of the growing season, Nimitz application results in little phytotoxicity to crops.

Organophosphate and carbamate nematicides act relatively slowly. Although high concentrations are lethal, the lower concentrations in soil generally kill by behavior modification. The affected nematodes typically are unable to move, find a host, feed, or find a mate. Eventually they die. If exposure to the nematicide is too short or at a too low concentration, however, these behavioral modifications can be reversed and the treatment is not effective. Both Nimitz and Velum Prime kill nematodes within the recommended dose ranges.

2. Non-chemical Management of Nematodes

Prevention of spread

Plant-feeding nematodes move only short distances under their own power, *i.e.*, a few inches to a few feet. Nematodes are commonly spread by the movement of infested soil and/or infected plants by human activity. Sanitation and good cultural practices are the best preventive measures against nematodes. Obtain nematode-free transplants from reputable sources. Wash soil from machinery and tools before using them at another location. Nematodes may also be spread by wind, water, soil erosion, and animals.

Crop rotation

Rotation of crops is an effective and widely used cultural practice to reduce nematode populations in the soil. To be most effective, crops that are poor hosts or nonhosts of the target nematodes should be included in the rotation sequence.

Cover crops

Some plants commonly used as cover crops are naturally suppressive to certain nematode species, but no single crop is effective against all nematodes. The cover crop plant may be a nonhost and, therefore, the nematodes starve, their population being reduced as with fallow. Nematodes invade the roots of certain other cover crop plants, but they fail to reproduce. Yet, other “antagonistic” plant species exude chemicals from their roots that are toxic to nematodes, such as marigold and asparagus.

Green manures and soil amendments

In general, the incorporation of large amounts of organic matter into the soil reduces populations of plant-feeding nematodes. The decomposition products of some plants kill nematodes. These include butyric acid released during the decomposition of ryegrass and timothy, and isothiocyanates released during the decomposition of rapeseed and other plants in the genus Brassica. Maximum benefit of these “natural” nematicides is obtained when the plant material is incorporated into the soil as green manure. It is important to consult with a diagnostic lab or extension agent to make sure the treatment is appropriate for the nematode being controlled, as green manure treatments are not equally effective against all plant- parasitic nematodes. For example, rapeseed is effective against dagger nematodes but not lesion nematodes. Also keep in mind that varieties of the same green manure crop can differ in the amount of toxic chemical components in their cell walls and therefore differ in the amount of toxic byproducts released during decomposition.

For dagger nematode control, two years of rapeseed green manure is desirable, but it may be possible to realize the same benefit by growing two crops of rapeseed within one year. The following timetable is suggested for producing two rotations of rapeseed within one year:

- Prepare seedbed and plant rapeseed by late April or early May (plant only recommended winter rapeseed varieties).
- Turn under green rapeseed by early September. Prepare seedbed and plant second crop by mid-September.
- The second crop should be turned under in late spring after soil temperatures reach 45°F or higher.
- Ideal conditions for incorporating the cover crop are similar to those required for obtaining the maximum benefit from fumigation (*i.e.*, the soil should be above 45°F and moist).
- Alternatively, planting dates may be reversed so that the first planting is in the fall followed by a second crop planted in the spring. This would end the rotation cycle in fall of the following year.

Some rapeseed varieties are more effective at suppressing nematode populations than others, and some varieties will not over-winter (*i.e.*, spring types) or they bloom too early in summer to be useful. The winter varieties 'Dwarf Essex' and 'Humus' work well for both spring and fall planting dates. If planted in the spring, these varieties grow vigorously to crowd out weeds and do not go to seed.

Tips:

- Rapeseed requires a firm, smooth seedbed that is free of weeds, heavy residue, and large clods.
- Seed may be drilled or broadcast. Seed at a depth of 3/8 inch and avoid planting too deep! If seed is broadcast, a cultipacker may be used to cover seed.
- A seeding rate of 7–8 lb/A works well.
- Rapeseed is sensitive to broadleaf herbicide carryover.
- Fall-planted rapeseed should have 8–10 true leaves and a 5-6-inch tap root with a 3/8-inch diameter root neck before the ground freezes.
- Sulfur is necessary for rapeseed to produce nematicidal compounds. Some soils may be deficient in sulfur. A soil test for sulfur may be beneficial.

Keep in mind that some biofumigant crops like rapeseed and sorghum-sudangrass are hosts for nematodes and it is not until incorporated into the soil as green manure that they will suppress nematode populations.

Plant nutrition and general care of the plant

The harmful effects of nematodes on plants can be reduced by providing plants with adequate nutrition, moisture, and protection from stress.

Fallow. Fallow is the practice of keeping land free of vegetation for weeks or months by frequent tilling or applying herbicides. In the absence of a host, nematodes gradually die out; however, eggs of some nematodes may survive for years in the soil. Because fallow may be destructive to soil and the land is out of production during that time, extended periods of fallow are not recommended.

Integrated management practices. Each of the practices mentioned above reduces the soil population of plant-feeding nematodes to varying degrees. Each practice has limitations and the degree of nematode control achieved depends on environmental factors, as well as the particular nematode and crop being considered.

Maximum benefit is realized when several of these practices are employed in an integrated crop management program. Because the host range of different nematode varies, the selection of cover crops, rotation crops, and green manures will be determined by the kinds of nematodes present. No single practice is a "cure-all" for all nematode problems.