

Sweet Potato Harvest, Curing and Storage Ramón Arancibia

Sweet potato [*Ipomoea batatas* (L.)] harvest is approaching, so this article will review practices and recommendations for sweet potato harvest, curing and storage for produce growers in Missouri. Sweet potato is a tropical, warm-season perennial crop originated in South America (known as batata or camote), but grown as an annual in the U.S. It is a member of the morning glory family and its commercial part is the enlarged storage roots. It is not a “yam”. This term is used mainly for marketing purposes. The true “yam” (*Dioscorea* spp.) is a completely different plant species from a different plant classification family.

Southern states and the west coast produce most of the sweet potato in the U.S., but there were 147,500 acres planted in 2019, up from 115,700 acres in 2013. This corresponded to a total production of almost 32 million cwt (100lb) valued at \$588 million (USDA–NASS, 2020, Vegetables 2019 Summary). Demand for fresh and processed sweet potatoes grown in the U.S. extends throughout the U.S. up to Canada and Europe. Primary supply is fresh market, but processed sweet potato has increased recently. Fresh market demands attractive medium size roots of uniform shape that are free from blemishes (U.S. No.1). This class brings the highest price; however, there has been a recent increase of bagged small storage roots sold as fingerlings or nuggets in the fresh market.

When to harvest?

Sweet potato storage roots grow as long as conditions (temperature and moisture) are favorable, so they never really “mature” or “ripen”. Therefore, the highest proportion of U.S. No.1 size (**table 1**) usually determines time of harvest because of the fresh market value. Small growers with direct sale

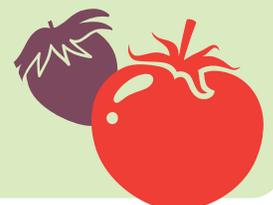
market, however, can sell all sizes as fresh sweet potato, so they may delay harvest to get the highest yield, but when soil temperatures fall below 60°F, sweet potato stops growing. Furthermore, sweet potatoes cannot tolerate freezing, so harvest them before the first freeze for best quality.

Table 1 Excerpt from the U.S. Standards for Grades of Sweet Potatoes.

Grade	Standard	Size
U.S. No.1	Consists of sweet potatoes of one type which are firm, fairly smooth, fairly clean, fairly well shaped, which are free from freezing injury, internal breakdown, Black Rot, other decay or wet breakdown, and free from damage caused by secondary rootlets, sprouts, cuts, bruises, scars, growth cracks, scurf, Pox (Soil Rot), or other diseases, wireworms, weevils or other insects, or other means.	<ol style="list-style-type: none"> 1. Maximum diameter shall be not more than 3-1/2 inches. 2. Maximum weight shall not be more than 20 ounces. 3. Length, unless otherwise specified, shall be not less than 3 inches or more than 9 inches. 4. Minimum diameter, unless otherwise specified, shall be not less than 1-3/4 inches.
U.S. No.2	Consists of sweet potatoes of one type which are firm and which are free from freezing injury, internal breakdown, Black Rot, other decay or wet breakdown, and free from serious damage, caused by dirt or other foreign materials, cuts, bruises, scars, growth cracks, Pox (Soil Rot), or other diseases, wireworms, weevils or other insects, or other means.	Unless otherwise specified the minimum diameter shall be not less than 1-1/2 inches and the maximum weight not more than 36 ounces.

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Pre-harvest

Sweet potato storage roots are prone to skinning that render unappealing roots for the consumer (**figure 1**). In addition, excessive skinning and bruising will shorten the roots shelf life since may cause roots to spoil or shrivel in storage. Therefore, growers take every effort to minimize skinning and bruising. The first cultural practice seven or more days prior to harvest is to remove vines and foliage, which promotes skin set and reduce skinning at harvest. Small growers use grass scythe, hedge trimmer or weed eater to remove the foliage and a disc coultter to cut vines. Large growers use a raised row shaped flail mower or a vine snatcher with coultters to cut the vines. Harvesting sweet potatoes when the soil is too dry increases skinning incidence, so harvest when soil separated easily without large clods. Good soil organic matter may help loosen the soil and reduce skinning.

Harvest

There are mainly two ways to dig the storage roots in commercial operations. With a chain digger that picks the storage roots with soil into a moving chain where the soil falls through while the storage roots continue and fall behind on top of the soil (**figure 2**). With a disc plow that turns the soil exposing the storage roots. Then, a crew picks and grades the storage roots by hand and put them in boxes accordingly. The crew uses gloves to minimize skinning. Large growers use more mechanized harvesters, in which the chain digger takes the storage roots up to a platform where the crew select the roots by size and put them in boxes. Another type of harvester includes rollers spaced according to the standard sizes to separate the storage roots and drop them into large boxes or bins.

Curing

Postharvest conditioning is necessary to enhance fast healing and reduce losses to decay and moisture loss because of injuries as well as to improve culinary attributes (sweetness, flavors, etc.). Cure sweet potatoes immediately after harvesting by placing them in a room at 85°F and 85% to 90% relative humidity for 5 to 7 days. It is important that the curing/storage rooms have fans for uniform distribution of the warm/humid air and air vents to maintain appropriate oxygen levels. Curing helps to speed up the healing of wounds that occur during harvest, preventing shriveling and reducing the risk of rot during storage. Curing also makes the sweet potato more palatable by converting starches to sugars and improving aroma and texture. The aesthetic appearance of storage roots depends on how fast the roots are put in curing conditions to generate a new skin similar to the original (**figure 3**). A delay in curing may cause the wound to dry out leaving unappealing scars.

Curing rooms are usually the same storage rooms, but at 85°F for the curing. The size depend on the volume and length of the harvest period. The rooms should be large enough to hold the volume of 3-4 days of harvest and then close it to complete the curing period. After curing, stop heating to allow room and storage roots to cool down, but never below 58-60°F because sweetpotato is chilling sensitive and physiological disorders such as “Hard Core” may occur.

Storage

Under the right storage conditions (58-60°F, 80%-90% humidity), properly cured sweetpotatoes can be stored for over six months. Roots should be kept in a dark, cool place after curing. If roots are stored above 60°F for extended periods, sprouting may start. Some growers reduce the relative humidity to promote skin set and toughness before washing and packing for delivery to markets. Reducing the humidity too early promotes moisture (weight) loss.

Yield

Variety, location and management influence sweet potato yield and proportion of root sizes. With acceptable management practices, yield may range from 150 to 350 bushels (50lb) per acre of U.S. No.1 roots, the preferred size for fresh market (**table 1**). A 50% to 60% of the harvest should correspond to U.S.No.1, so total harvest could reach 300 to 700 bushels per acre. In general, growers separate and classify the rest into small roots as canners (diameter between 1-1/2 and 2 inches) and large ones as jumbos (diameter above 3-1/2 inches). Under exceptionally good conditions and irrigation, total yields of 800 to 1,000 bushels per acre are possible in southern states (**Figure 4**).



Figure 1 Sweet potato storage roots with sunken leathery scars from skinning because of inappropriate healing conditions.



Figure 2 Chain digger dropping sweetpotato storage roots after sieving the soil through the chain.



Figure 3 Wound healing and generation of new skin: sunken dry wound scars (left) and new skin generated when curing immediately after harvest (right).



Figure 4 Harvest of sweet potato ‘O’Henry’ (white flesh); total yield over 800 bushel per acre.

Powdery Mildew vs. Gray Mold on Tomato David Trinklein

The incidence of fungal molds on greenhouse and high tunnel tomatoes has increased in recent years. While crop rotation would help to mitigate the problem, the high dollar value of tomato makes this an unattractive option to most growers. Therefore, disease management practices are extremely important for a successful crop. Accurate pest identification is the foundation on which a good disease management program is built. If a disease is not properly identified, the chances of selecting the correct management strategies are greatly reduced. Two troublesome tomato leaf disease that lately have been mistaken for each other are powdery mildew and gray mold.

Gray mold on tomato is caused by the fungus *Botrytis cinerea* which is a common pathogen of many plant species. Symptoms include light tan or brownish v-shaped spots on the leaves, beginning at their margins. Later, fluffy gray spores cover the surface of the spots and, ultimately, the leaf collapses and dies. The fungus also can cause cankers on stems and kill flowers and fruit. Gray mold is most virulent when the environment is cool (60-70° F) and the relative humidity is high (≥ 80%). Therefore, greenhouse and high tunnel tomatoes are especially at risk, especially early in the season before temperatures warm.

The epidemiology of powdery mildew is a bit more complex. There are several species of fungi that can cause tomato powdery mildew; symptoms vary with causal organism. The relatively recent outbreak of tomato powdery mildew in Missouri has been attributed to the fungus *Oidium lycopersicum*. Disease symptoms appear as powdery, white colonies of mycelium on the upper surface of leaves. Yellowing, necrosis and defoliation can result as the disease progresses.

The powdery mildew fungus produces airborne spores which land on leaves, germinate and infect the plant when favorable environmental conditions exist. The latter includes moderately temperatures (between 50 to 95° F) and high relative humidity. The increase in greenhouse and high tunnel tomato production in Missouri has led to the creation of more tomatoes being produced under ideal conditions for the disease to become problematic.

Cultural control of both gray mold and powdery mildew begins with keeping relative humidity within the greenhouse or high tunnel as low as possible. This can be a problem early in the season when temperatures are cool and fans are off, or sides dropped in the case of high tunnels. Later, when plants become large, lack of adequate air circulation within the leaf canopy aids to high humidity problems.

Encouraging good air movement by adequate plant spacing and leaf pruning helps to lower the humidity around the leaf surface. Additionally, good sanitation practices including the removal of all plant debris between crops helps to reduce inoculum of the diseases but will not prevent them entirely.

Additionally, strict sanitation is very important for the control of both diseases, since infected leaves carry inoculum that than be transferred to succeeding plantings. Therefore, tomato

growers utilizing greenhouses or high tunnels should develop a “start clean, stay clean” attitude. Make sure that all plant debris from the previous crop is eliminated between crops. Soil preparation via deep plowing can help rid the production area of remaining inoculum on plant debris that might have been missed.

A number of fungicides have been recommended for tomato powdery mildew by the Midwest Vegetable Production Guide (<https://ag.purdue.edu/btny/midwest-vegetable-Pages/default.aspx>). These include:

Brand Name	Active Ingredient	FRAC#	Brand Name	Active Ingredient	FRAC#
Aprovia Top	difenoconazole + benzovindiflupyr	3 + 7	Quadris	azoxystrobin	11
Cabrio	pyraclostrobin	11	Quadris Opti	azoxystrobin + chlorothalonil	11 + M5
Inspire Super	difenoconazole + cyprodinil	3 + 9	Quadris Top	azoxystrobin + difenoconazole	11 + 3
Luna Sensation	fluopyram + trifloxystrobin	7 + 11	Quintec	quinoxifen	13
Luna Tranquility	fluopyram + pyrimethanil	7 + 9	Rally	myclobutanil	3
Miravis Prime	pydiflumetofen + fludioxonil	7 + 12	Switch	cyprodinil + fludioxonil	9 + 12
Priaxor	fluxapyroxad + pyraclostrobin	7 + 11	Vivando	metrofenone	U8

Correspondingly, the following fungicides are labelled for the control of gray mold on tomato:

Brand Name	Active Ingredient	FRAC#	Brand Name	Active Ingredient	FRAC#
Botran	dichloro-nitroaniline	14	Luna Tranquility	fluopyram + pyrimethanil	7 + 9
Cabrio	pyraclostrobin	11	Miravis Prime	pydiflumetofen + fludioxonil	7 + 12
Various formulations	chlorothalonil	M5	Orondis Opti	oxathiapiprolin + chlorothalonil	49 + M5
Inspire Super	difenoconazole + cyprodinil	3 + 9	Pageant Intrinsic	boscalid + pyraclostrobin	7 + 11
Endura	boscalid	7	Priaxor	fluxapyroxad + pyraclostrobin	7 + 11
Fontelis	penhopyrad	7	Scala SC	pyrimethanil	9
Luna Sensation	fluopyram + trifloxystrobin	7 + 11	Switch	cyprodinil + fludioxonil	9 + 12

Please note that Cabrio, Luna Sensation, Luna Tranquility and Switch are the only fungicides labeled for both powdery mildew and gray mold control

Finally, genetic resistance is the easiest and least expensive way to control any disease. There are a few new tomato varieties that are advertised to have “intermediate resistance” to powdery mildew. Examples include ‘Climstar’, ‘Ducovery’, ‘Federik’, ‘Foronti’, ‘Geronimo’, ‘Granadero’, ‘Rebelski’ and ‘Touché’.

Unfortunately, there are no tomato varieties that carry genetic resistance to gray mold.

Fungicide Groups and Resistance Management

Ramón Arancibia

Fungicides are effective tools in a plant disease management program. They halt or inhibit infection, growth and/or reproduction of the target fungal pathogens and can be effective in preventing or minimizing the incidence of target plant diseases. Commercial fungicides contain one or more active ingredients each with a specific mode of action. Therefore, selecting the appropriate fungicide for the target plant pathogen, application time and method for full coverage is critical for disease control.

Fungicides are categorized as either protectant or systemic depending on their capacity to be absorbed by the plant tissue. Protectant fungicides provide a protective barrier on the surface of the plant tissue to prevent infection by fungal pathogens, so they are active only on the surface of plants, are susceptible to weathering, and need to be applied frequently to cover new growth. Systemic fungicides are absorbed into the plant tissue. They can move a short distance within the tissue or reach the vascular system and translocated to other parts of the plant. Therefore are less susceptible to weathering. Nonetheless, fungicides are preferable applied before favorable conditions for infection occur to prevent infection and disease development.

Fungicides inhibit fungal growth by interfering with critical pathogen metabolic processes. Their active ingredients have a particular mode of action, which refers to the specific cellular process inhibited. Those fungicides that disrupt cellular functions in multiple places or different metabolic processes in the biology of the fungal pathogen are multisite inhibiting fungicides or have broad-spectrum activity. Fungicides that disrupt only one single site or cellular function are site-specific or have narrow-spectrum activity. Site-specific fungicides are at higher risk of the pathogens to become resistant to it because pathogens are more likely to overcome single site inhibition than multisite inhibition. Most of the new and/or systemic fungicides are site-specific.

Fungicide resistance has become a serious widespread problem in plant disease management. Fungicides become less effective when the pathogen becomes less sensitivity to the fungicide and disease develops even when applied at recommended rates, which were effective previously to the original sensitive pathogen population. Because of the genetic variability in wild-type pathogen population, the probability that the fungicide does not affect a few individuals (strain) is high. With repeated applications of the same fungicide, these individuals will survive and continue reproducing until the resistant strain dominates the pathogen population. Therefore, fungicide resistance in a pathogen population becomes important when the fungicide-resistant population outnumber the fungicide-sensitive population. Then, resistance may become a stable, inheritable adaptation of the pathogen population. Therefore, fungicide resistance is a fungus acquired heritable reduction in sensitivity to a specific active ingredient (or fungicide) and it means reduced or no disease control after a correct application.

Inappropriate use of fungicides with the same mode of action can lead to resistance. Repeated or incorrect use of a fungicide promotes the buildup of the resistant population. Resistance may occur gradually or suddenly depending on how much and for how

long fungicides with similar mode of action are used. Therefore, the fungicide mode of action, pathogen genetics and cultural practices influence the development and how fast the fungicide resistance appears within the pathogen population.

The Fungicide Resistance Action Committee (FRAC) is a Specialist Technical Group of CropLife International (CLI; Formerly Global Crop Protection Federation, GCPF) that provide fungicide resistance management guidelines to prolong the effectiveness of “at risk” fungicides and to limit crop losses should resistance occur. Among their main aims are to identify existing and potential fungicide resistance problems and provide guidelines and advice on the use of fungicides to reduce the risk of resistance developing, and to manage it should it occur.

Fungal pathogens that become resistant to one fungicide (active ingredient) likely are resistant to other fungicides with the same or similar mode of action (cross-resistance). Consequently, FRAC developed fungicide group code numbers, referred to as FRAC codes, to educate and facilitate management of pathogen resistance. Fungicides with the same FRAC code have a similar mode of action and could exhibit cross-resistance. All fungicides with one or more active ingredients list the FRAC code(s) for their active ingredients in the front of the label. FRAC updates and publishes the full list of the codes for all fungicide common names (active ingredients), their modes of action and the risk level (low, medium or high) for fungicide resistance development annually and it can be found at <https://www.frac.info/>.

The FRAC code number on product labels was assigned primarily according to the time of product introduction to the market. Then, letters and numbers were assigned to distinguish the fungicide groups according to their mode of action and cross-resistance behavior. The mode of action code to classify fungicides consists of two parts. A letter (A, B, etc.), which refers to the mode of action in a pathogen’s biology and a number, which refers to specific biochemical target sites. The mode of action grouping is according to processes in the metabolism starting from nucleic acids synthesis (A) to other secondary metabolic processes (B to D), e.g. respiration (C). Additional groups include host plant defense inducers (P), those with an unknown mode of action and unknown resistance risk (U), and fungicides with multi-site inhibitors (M). Fungicidal products of biological origin are grouped according to the main mode of action within the respective pathway categories. A more recently introduced category is “Biologicals with multiple modes of action” (BM), which are of biological origin. If available, the biochemical mode of action is given.

FRAC provides information on the mechanism of resistance and the resistance risk. There is increasing evidence that the degree of cross-resistance can differ between group members and pathogen species or even within species. For the latest information on resistance and cross resistance status of a pathogen/fungicide combination, it is advised to contact local FRAC representatives or product manufacturer’s representatives.

Soil-borne Disease Control using Biofumigants

David Trinklein

The repeated cropping of land year-after-year to the same species such as tomato has resulted in the buildup of diseases. This especially is true in structures such as greenhouses and high tunnels. Left unchecked, soil-borne diseases such as such as *Fusarium* and timber rot have the potential to cause significant economic loss.

Control of troublesome soil-borne pathogens of vegetable crops historically was accomplished using soil fumigants such as methyl bromide. Due in large part to its adverse effect on the Earth's ozone layer, methyl bromide has been phased out of agricultural use. Replacement fumigants such as chloropicrin, Basamid® (dazomet), and Vapam® (metham sodium) are available. However, there are problems associated with the use of these compounds as well.

Synthetic chemical fumigants most often are applied as gases injected into the soil or as granules that release the active ingredient. Because of the inherent toxicity of chemical fumigants and the possibility of off-gassing from treated sites, the use of these compounds is rigidly controlled by the government. Applicators must be trained and certified to use these compounds in a legal manner. Additionally, they tend to be expensive. Thus, growers are seeking viable alternatives to replace traditional chemical fumigation as a means of managing soil-borne diseases.

Biofumigation represents one such alternative. Biofumigation involves the use of plants, mainly from the *Brassicaceae* (or mustard) plant family, to both control soil-borne diseases and improve soil health. Many members of the mustard family contain compounds known as glucosinolates (GSLs). The latter are organic compounds that contain sulfur and are responsible for the pungency in crops such as mustard, cabbage and horse radish. They are present in the stem, leaves, roots and seeds of plants containing them.

Upon hydrolysis after plant tissue has been incorporated into the soil, the GSL contained releases chemicals known as isothiocyanates. Isothiocyanates have both fungicidal, nematocidal and weed suppressive properties. Methyl isothiocyanate, a synthetic isothiocyanate, is the compound that serves as the active ingredient for chemical soil fumigants such as metam sodium. Thus, the same toxic compound found in synthetic fumigants can be supplied by plants, but at much lower concentrations. Biofumigants, therefore, pose much less risk to the environment and carry fewer governmental regulations.

Recent studies have demonstrated that growing brown mustard (*Brassica juncea*) as a cover crop and then thoroughly incorporating it into the soil can reduce weed pressure, parasitic nematodes, and soil-borne pathogens (e.g. *Pythium*, *Rhizoctonia*, *Sclerotinia*, *Verticillium* & *Phytophthora*). The mode-of-action is much the same as with chemical fumigants, but on a greatly reduced scale.

A resistance management program should integrate resistant varieties, good cultural practices and appropriate use of fungicides. Take in consideration that the strategy to manage fungicide resistance focus at slowing down the development of resistant pathogen populations. Therefore, resistance management plans must be implemented before resistance becomes a problem with at-risk fungicides available for a particular use. The resistance management program is to minimize the use of at-risk fungicides without compromising disease control.

Although specific strategies vary depending on the fungicide FRAC code, the target pathogen and crop, the general approach is similar:

1. Whenever feasible, resistant crop varieties should be selected. The use of resistant varieties reduces the potential for disease development, incidence and severity.
2. Appropriate sanitation and crop rotations can reduce source of inoculum, while proper soil fertility can reduce disease incidence.
3. Avoid environmental conditions favorable for disease development and sites with a history of disease problems. These practices will minimize or eliminates the use of fungicides.
4. The use of fungicides is the last resort for disease management when alternatives are not available to avoid the development of fungicide resistant populations.

The following practices should be used when fungicides are necessary:

1. Accurate disease diagnosis and/or pathogen identification for appropriate fungicide selection (fungicides differ in their effectiveness to control different diseases).
2. Use low-risk fungicides when possible.
3. Start fungicide applications when conditions are favorable for disease development.
4. Use appropriate application equipment/methods for full spray coverage.
5. Do not apply a fungicide more than two times sequentially. Alternate fungicides from different FRAC codes.
6. Alternatively, mix at-risk fungicides with a fungicide with multisite action and/or of different mode of action. Refer to product labels to ensure fungicides are compatible or already a pre-mix.
7. Follow the label for rates and specific resistance management guidelines. The label is the law.

The use of mustard as a biofumigant can be accomplished in two ways: 1) grow it as a cover crop and incorporate it into the soil, or 2) apply mustard meal derived from ground mustard seeds and incorporate it into the soil.

Strains of mustard selected for high GSL content are commercially available for use as biofumigants. Rupp Seeds (800-700-1199) markets the Caliente series of mustards which have been used successfully in university trials. Alternatively, Mighty Mustard® (509-487-0755), a Washington-based company, markets its own series of biofumigant mustard. It must be noted, because of their high GSL content, biofumigant mustards are *not* suitable for livestock grazing.

After a suitable seedbed is prepared, biofumigant mustards are broadcast seeded at the rate of about 10-15 lbs./acre, or .5 lbs./1,000 sq. ft. Lightly working the seeds into the soil improves germination which occurs in about five to seven day, depending upon soil temperature. The greater the plant growth, the greater the amount of GSL available for soil incorporation. Therefore, adequate water should be supplied and other best management practices followed.

The GSL concentration in mustard plant material is at its highest just before full-bloom (about 60-80% of the plants are flowering). At this time the above-ground growth must be chopped as finely as possible. GSL release increases as plant particle size decreases. If available, the use of a flail mower is recommended in order to shred the plant material thoroughly.

Immediately after shredding, the biofumigant crop should be incorporated thoroughly into the top five to eight inches of soil using an implement such as a rotary tiller, and not simply turned under with a plow. Research has demonstrated that 80% of the GSL present in the plant tissue shredded will be released within 20 minutes after mowing. Therefore, time is of the essence. Once the plant material has been incorporated, the soil should be watered and sealed with a tarp or sheet of plastic to trap the GSL and its breakdown gases in the soil.

After 14 days have passed, the tarp/plastic may be removed, since all of the plant material will have decomposed by that time. Attempting to plant the area prior to the passage of two weeks could result in significant crop injury or hinder seed germination.

Alternatively, mustard meal such as Pescadero Gold™ (831-763-3950) can be used to incorporate GSL into the soil instead of growing mustard plants. While this practice is more expensive, it will result in a higher amount of GSL being released into the soil resulting in superior disease control and weed suppression. Using this method, 1 lb. of mustard meal per 45 sq.ft. of soil is applied and thoroughly incorporated into the soil. As above, water the soil and seal with a tarp or layer of plastic, in the case of mustard meal, for at least three weeks.

Depending on mustard strain and supplier, biofumigant mustards seeds for a 30 x 100 ft. high tunnel would cost less than \$10. Mustard meal (Pescadero Gold) would cost about \$130, if purchased in 50 lb. bags.

Finally, allyl isothiocyanate, the active ingredient in mustard tissue and mustard meal, has been synthesized and is commercially available under the brand name of Dazitol (Champon Millennium Chemical; 703- 349-0511). In addition to suppressing nematode populations, it is advertised to control soil borne fungi including Fusarium (oxysporum and Solani), Pythium, Rhizoctonia, Phytophthora, Pyrenochaeta, Sclerotium, Armillaria, and Plasmodiophora. Since it is considered to be a soil fumigant, read and follow label directions carefully.

In summary, biofumigation tends to suppress rather than totally eliminate soil-borne pathogens as do chemical fumigants. Therefore, it must be used as part of an integrated disease management program. The elimination of diseased tissue, crop rotation and (when available) the use of resistant varieties should be considered as reduce crop loss from soil-borne diseases.

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