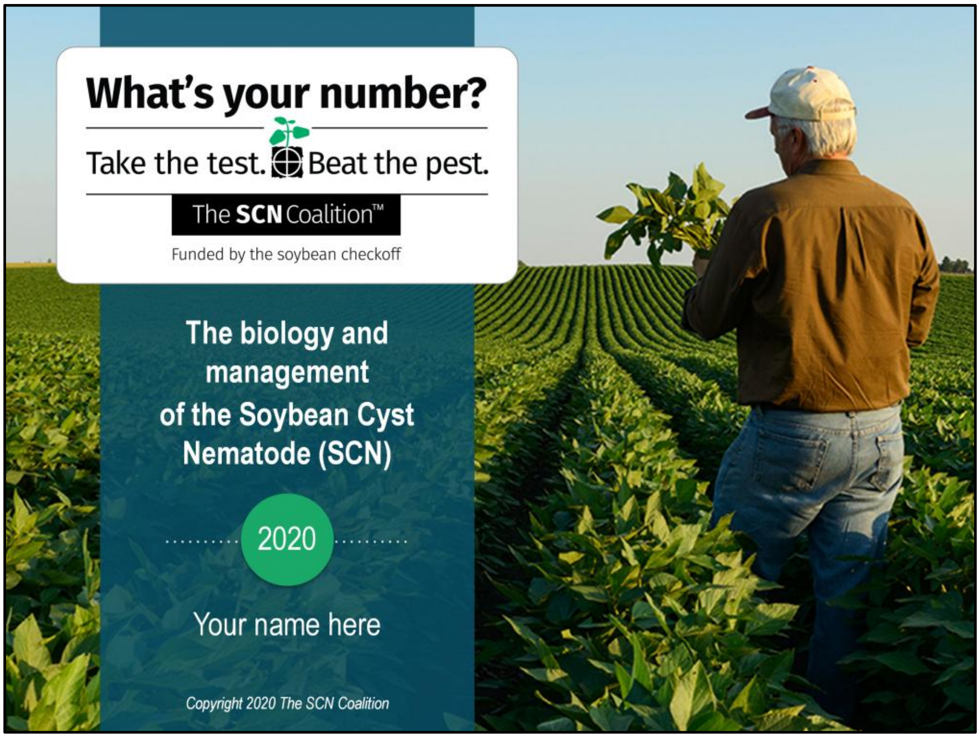
What's your number?
Take the test. Beat the pest.
The SCN Coalition™
Funded by the soybean checkoff
The biology and management of the Soybean Cyst Nematode (SCN)
2020
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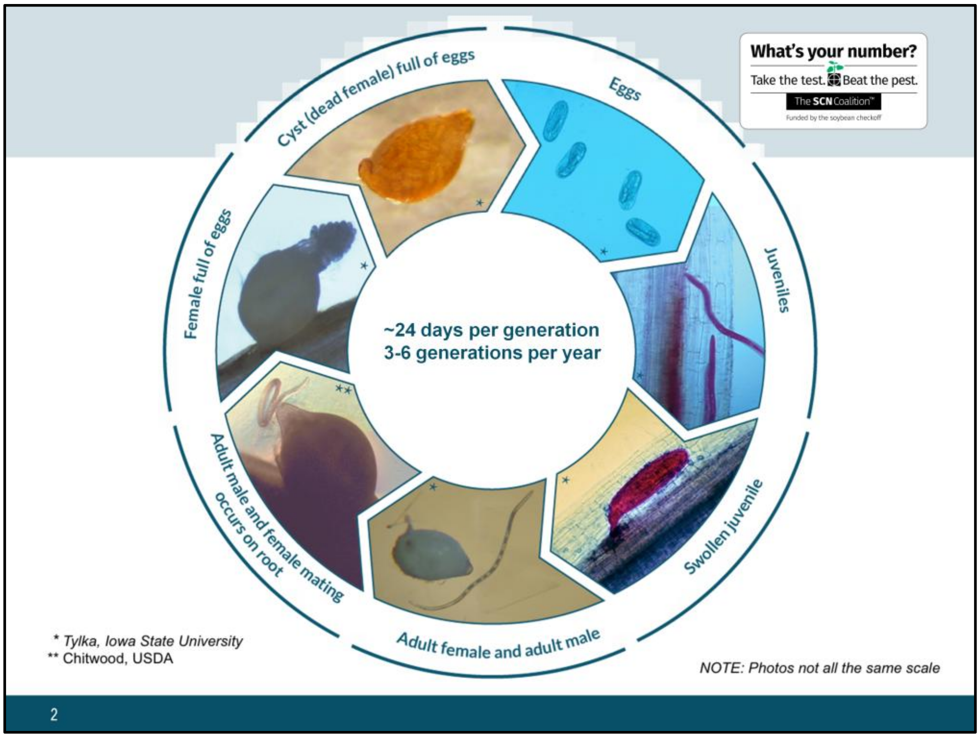
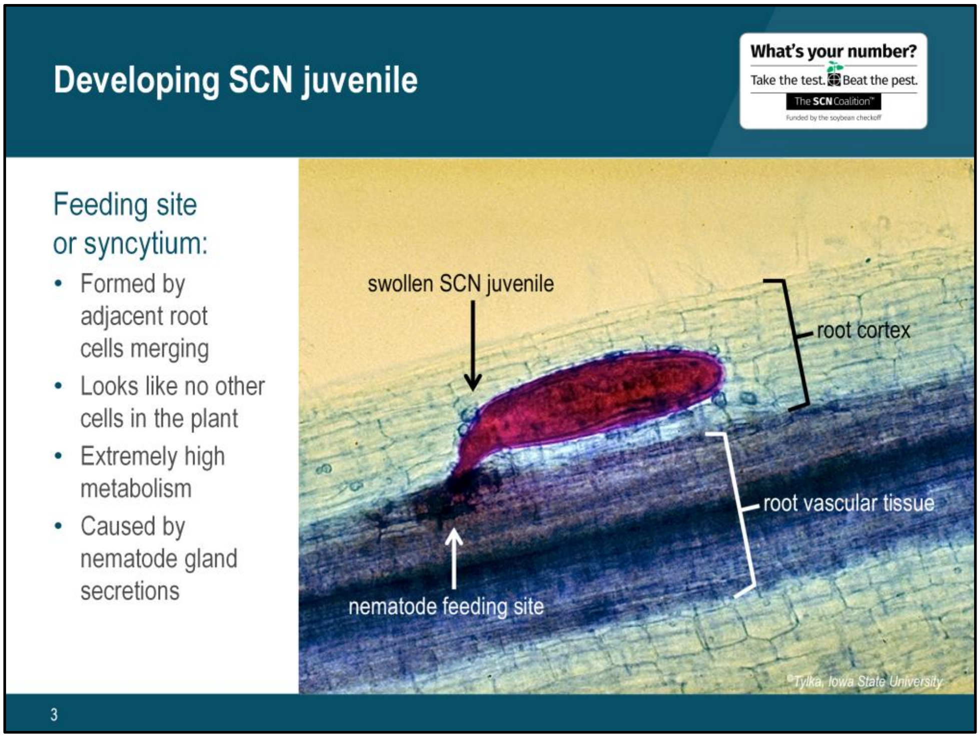


SCN is a worm that lives in the soil. There are many other nematodes in the soil that are beneficial to agriculture and soil health. SCN is not like most nematodes, SCN starts out as a tiny, microscopic egg, and a **juvenile worm** hatches out of the egg. The juvenile is a weak link in the life cycle because it is vulnerable to being eaten and to starvation. The juvenile needs to get into a soybean root to be protected and to develop. When the **juvenile** gets into the soybean root, it burrows to the center of the root to the vascular tissue. Once it attaches to the plant's vascular tissue, the juvenile starts to feed, develop, and swell.

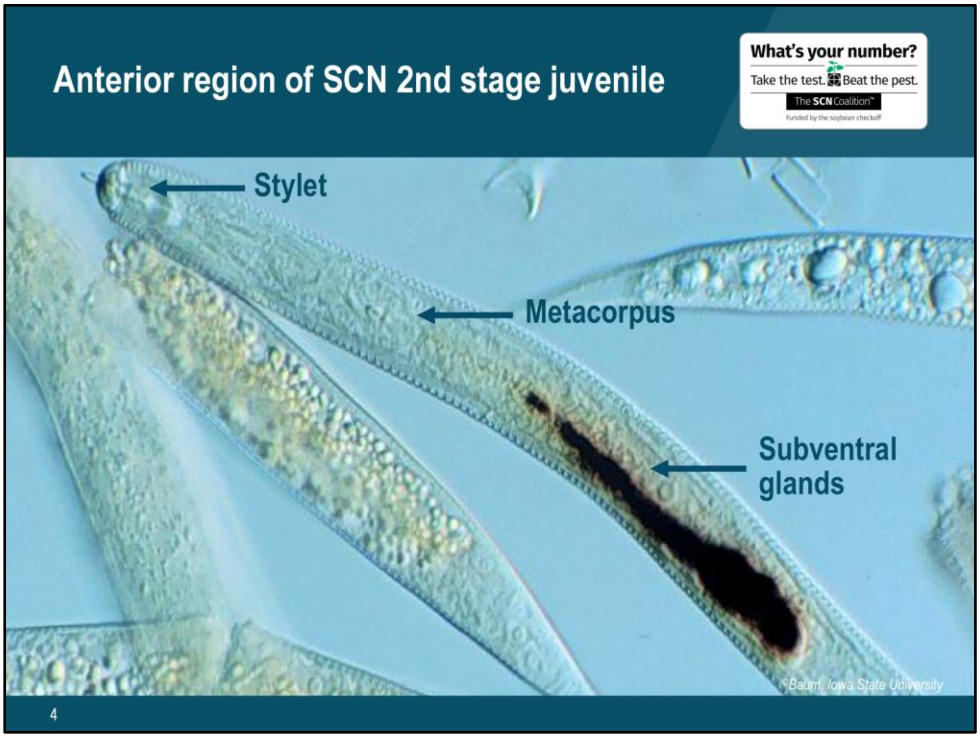
In the third photo on this slide, the juvenile is no longer worm shaped because it has fed for several days. At this point, the swollen juveniles of males or females look identical. But this swollen juvenile is as large as a male gets. If this swollen juvenile is to become a **male**, it changes back to a worm shape, leaves the root, and goes back into soil. In the photo on the bottom, the adult male looks like a long, larger version of a juvenile. (Photos aren't all the same scale.)

If the swollen juvenile is going to become an adult female, it continues to enlarge throughout its life until it takes on a lemon shape. Adult females stay attached to the root and feed throughout their life cycle. The female gets so large that she ruptures out of root and is exposed on the surface of the root. Then the **female** releases a chemical signal to attract males, and they mate. A female will be mated by multiple males, and males will mate with different females resulting in a lot of genetic mixing. After **mating**, the female makes about 50 eggs outside of her body, in a clump called an egg mass, and then she fills up with 250 or more eggs internally. The total number of eggs produced by a single female can be 300 or more. After producing eggs, the **female dies**, and the body wall becomes brown, tough and leathery, and hardens to form the cyst – a swollen, dead female full of eggs.

In the middle of summer, when soils are warm, **the life cycle** takes about 24 days to be completed. So if soybeans are growing in a field for 4 months, there can be 3-6 generations of SCN produced in a single growing season.



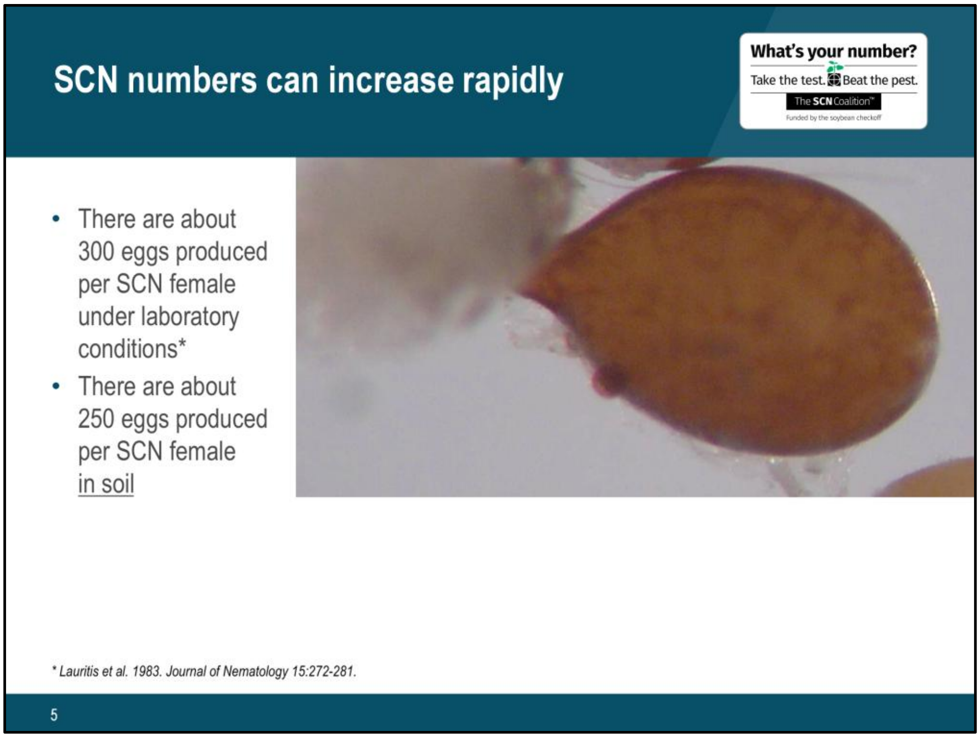
Here is a closer look at the image of the swollen juvenile, which is the most interesting.
In the image, the top shows the outer edge of the root. The vascular tissue is labeled in the center of the root and the swollen SCN juvenile is positioned mostly in the root cortex.
The dark area outlined in white around the head of the nematode is called the feeding site. The technical name is the syncytium (pronounced sin-sis-shum).
The syncytium is formed starting with one living plant cell, which merges with adjacent living root cells to form one big cell called the syncytium or feeding site.
The amazing thing is the syncytium looks like no other cells in the soybean plant. So the nematode goes in and changes a single plant cell to recruit cells from around it, and they all merge together and form something new that doesn't exist anywhere else in that soybean plant.
That feeding site or syncytium has extremely high metabolism, presumably to feed the nematode. That whole process of forming the syncytium is caused by something that the juvenile nematode is producing and injecting into the plant cell.



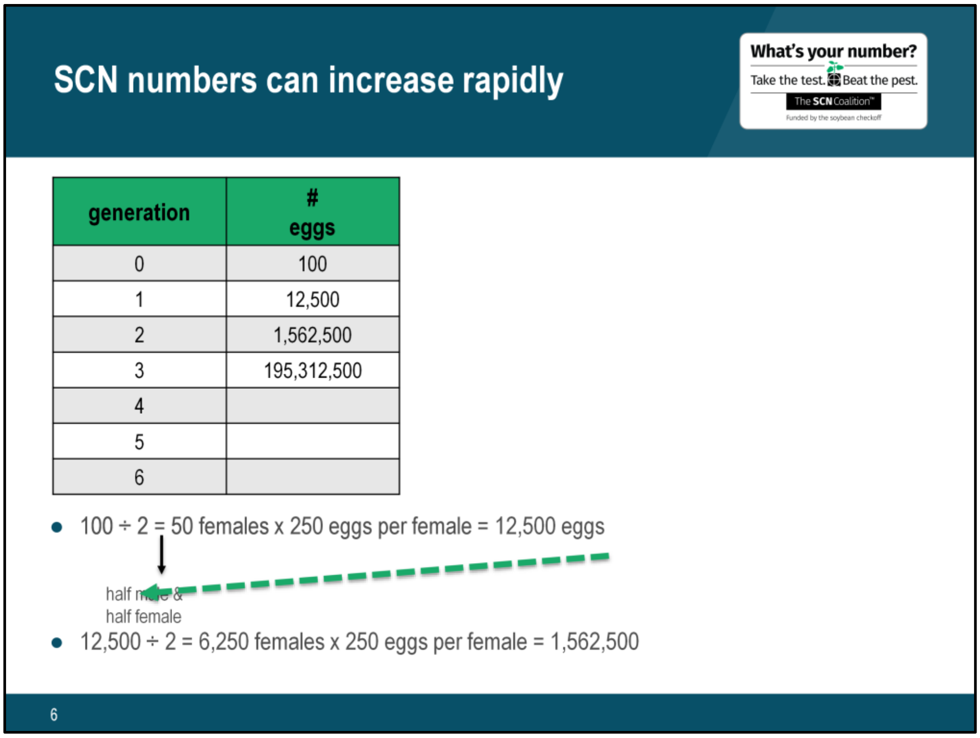
The hatched SCN juvenile has a pointed mouth spear, called a stylet, that it uses to puncture the plant cell. The spear is hollow, so the nematode can use it to inject substances into the plant cell, and also to withdraw substances (food) back into the nematode through the stylet.

We believe that one or more substances are produced in glands in the nematode juvenile's esophagus – two subventral glands and/or one dorsal gland – and injected into the plant cell to change it into a feeding site or syncytium.

This transformation is pretty amazing, and exactly what is happening is still one of the mysteries of the biology of SCN.



The biology of the soybean cyst nematode makes it difficult to manage, in two respects:
1) One is how quickly the populations build up.
2) Secondly is how well it survives.
This slide shows how quickly the numbers can build up. You see the dead female or cyst, and you see eggs inside and outside of the body.
In a study published in the 1980s, they measured an average of 300 eggs produced per female, either in the egg mass and inside the dead cyst. That's under laboratory conditions.
In nature, in soil, that number is about 250. For some reason nematodes aren't as prolific or productive growing in soil as in the laboratory.



Let's do some math. We'll start with 100 SCN eggs and do the math over six generations.

We take **100**, then divide by two because **half** of the individuals will become males and half will become females, and only females produce eggs.

So if **50 females** can produce **250 eggs** each, after one generation, we'll have **12,500 eggs**.

Now take **12,500 eggs** and do it all again… in **two turns** of life cycle, you'll have 1.56 million eggs.

You get a feel for how quickly these numbers could multiply.

Fortunately this doesn't happen in nature because of attrition.

SCN numbers can increase rapidly

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generation	0% attrition	97% attrition
0	100	100
1	12,500	12,500
2	1,562,500	46,750
3	195,312,500	175,250
4		657,250
5		2,464,750
6		9,242,750

Attrition = "a reduction or decrease in numbers, size, or strength"

- 100 ÷ 2 = 50 females x 250 eggs per female = 12,500 eggs
- 12,500 x **0.03** = 375 ÷ 2 = 187 females x 250 eggs per female = 46,750

97% attrition

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Attrition is the natural decrease in numbers that happens to populations of organisms in nature.

In nematode literature, published attrition rates are upwards of 90%. So let's use a 97% attrition rate.

Assuming a 97% attrition rate, let's do the math again.

We start with **100 eggs**, and wind up with 12,500 after the first generation. Then **attrition** kicks in.

From those 12,500 eggs, we'll assume **97% attrition** and only take 3% to adulthood, because 97% die off before becoming adults.

That brings us down to 375 individuals, of which only half are female. So that's 187 females multiplied by 250 eggs per female, and we're now at **46,750 eggs** after the second generation.

Even with 97% attrition, we go from 100 eggs to 9.2 million in six generations, which fortunately does not occur in nature.

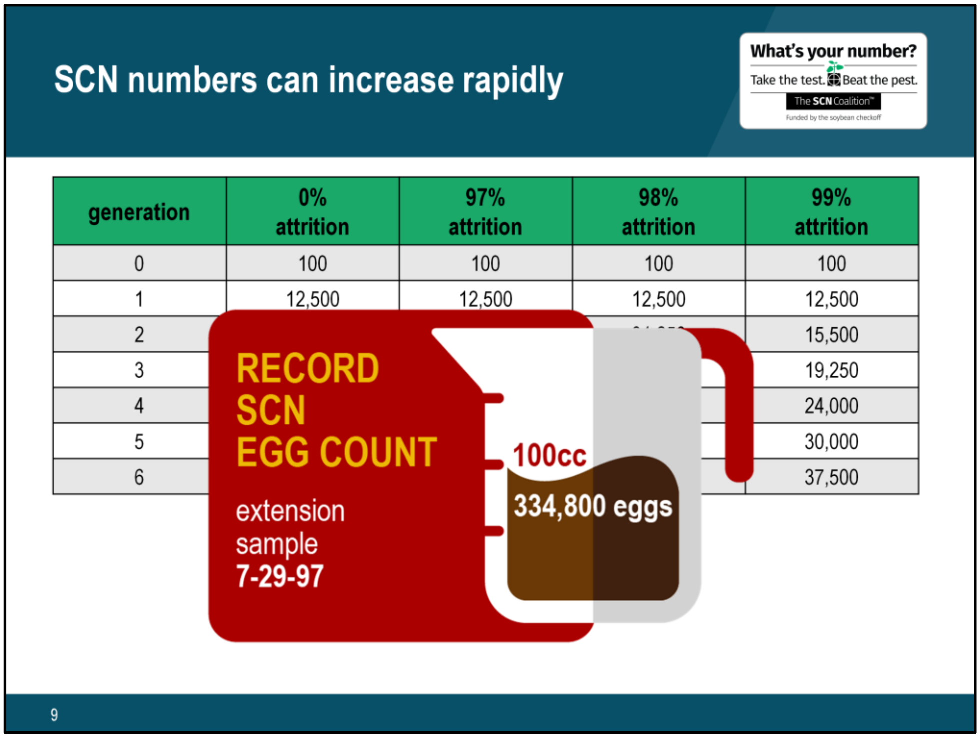
SCN numbers can increase rapidly

generation	0% attrition	97% attrition	98% attrition
0	100	100	100
1	12,500	12,500	12,500
2	1,562,500	46,750	31,250
3	195,312,500	175,250	78,000
4		657,250	195,000
5		2,464,750	487,500
6		9,242,750	1,218,750

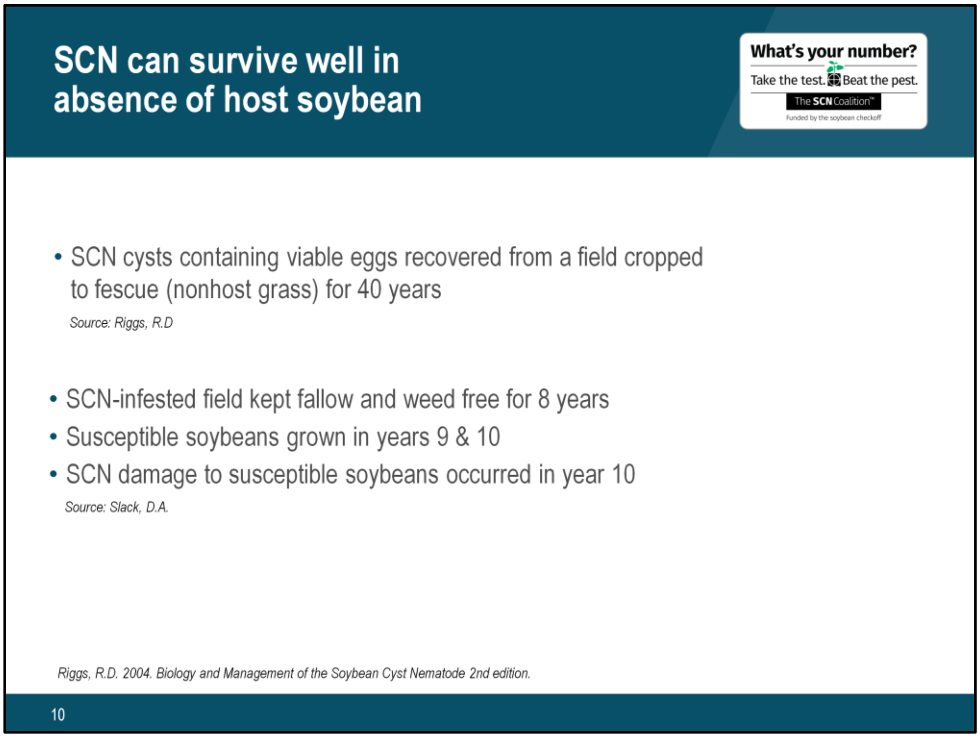
- 100 ÷ 2 = 50 females x 250 eggs per female = 12,500 eggs
- 12,500 x **0.02** = 250 ÷ 2 = 125 females x 250 eggs per female = 31,250

98% attrition

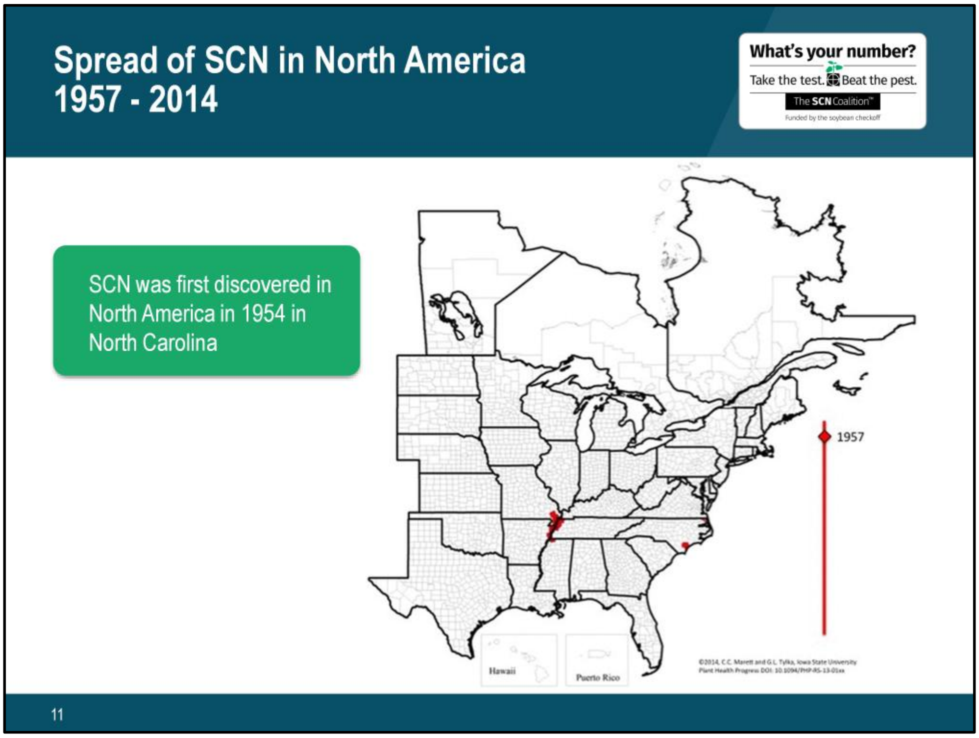
So let's take the attrition rate up to 98% - with only 2% of the population surviving to adulthood and reproducing.
In **six generations** over the summer, we see 1.2 million eggs.
I think this is still too high.



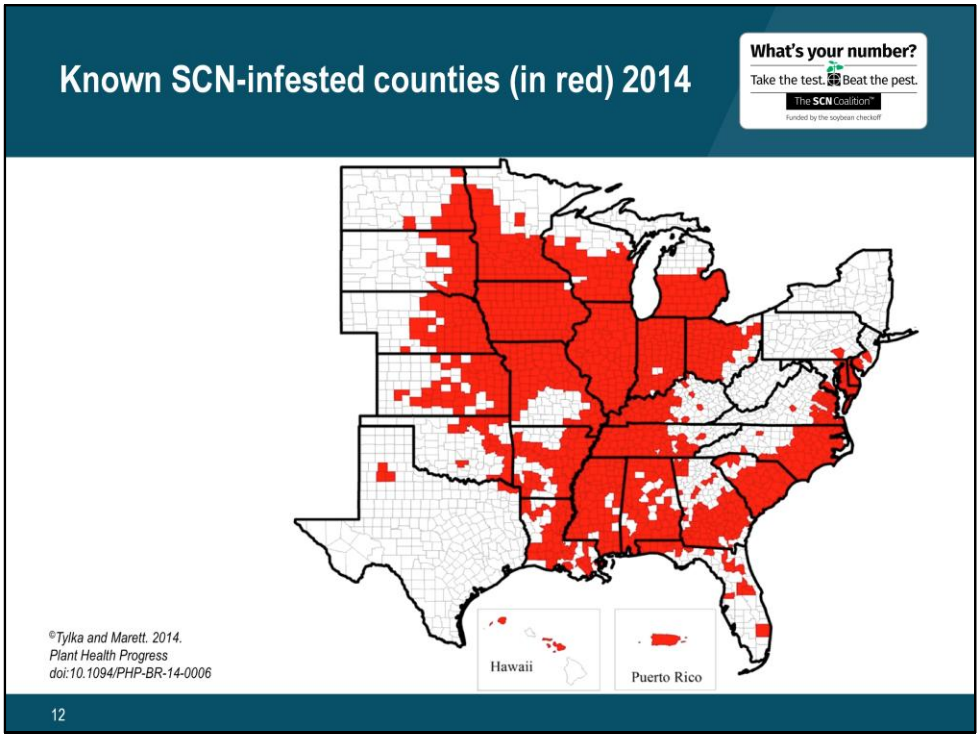
Finally, let's look at a 99% attrition rate. Even with 99% of the population not surviving to adulthood, 100 eggs can become 37,500 eggs in six generations.
That should give you some feel for the reproductive capability of soybean cyst nematode.
If you're wondering how high egg counts can get, here's **the record high** from the Iowa State University nematode testing lab. Their highest egg count ever recorded in a sample was 334,800 eggs. So crazy numbers can happen – not into the millions, but 334,800 was a real sample from a farm field.



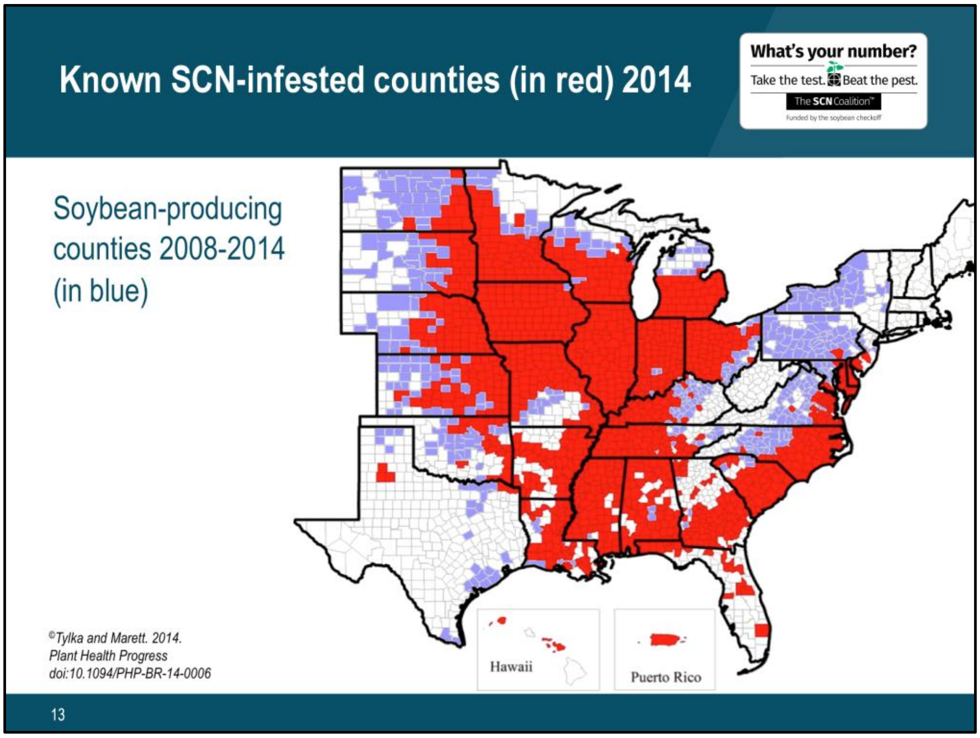
The other problem with soybean cyst nematode is that it can survive extremely well in soil.
Unfortunately there aren't a lot of good numerical data to substantiate this point, so we have to rely on our scientific forefathers. Dr. Bob Riggs from the University of Arkansas, considered by many to be the "grandfather" of SCN in the United States – references SCN survival in a book chapter he wrote.
Dr. Riggs describes how he recovered viable eggs from within SCN cysts in soil from an SCN-infested field that only had fescue (a non-host grass) grown for 40 years.
A contemporary of Dr. Riggs was **Dr. Derald Slack**, University of Arkansas. He described an SCN infested field that was kept free of plants (both planted plants and weeds) for eight years. Susceptible soybeans were grown in years 9 and 10, and by year 10, the soybeans were damaged by SCN.
So in general, we say SCN can probably live in the soil for 10 years or more.



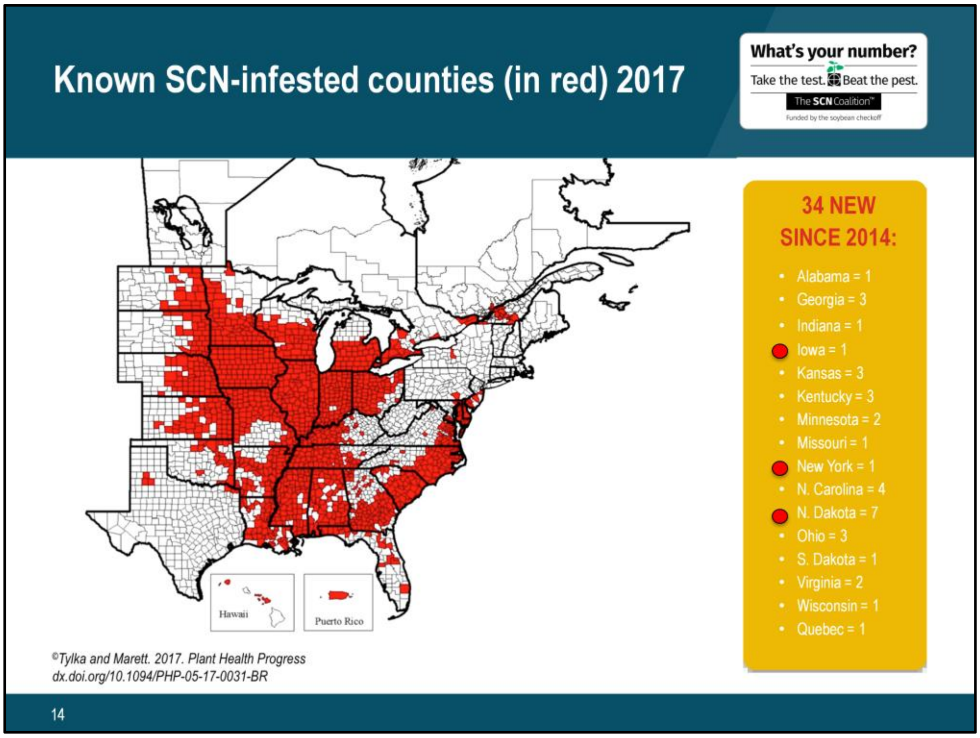
Soybean cyst nematode was first discovered in North America in the coastal region of North Carolina. It quickly spread from that area throughout the south.
Then it made a big jump to the bootheel of Missouri. It seems to have spread up and down the Mississippi River after that.
Then it makes another big jump up to the North Central U.S. in the late 1970s, and it seems to be spreading from there as well.
It's rapidly disseminating across the soybean-growing areas of the United States.



Here's what the SCN infestation map looked like in 2014.



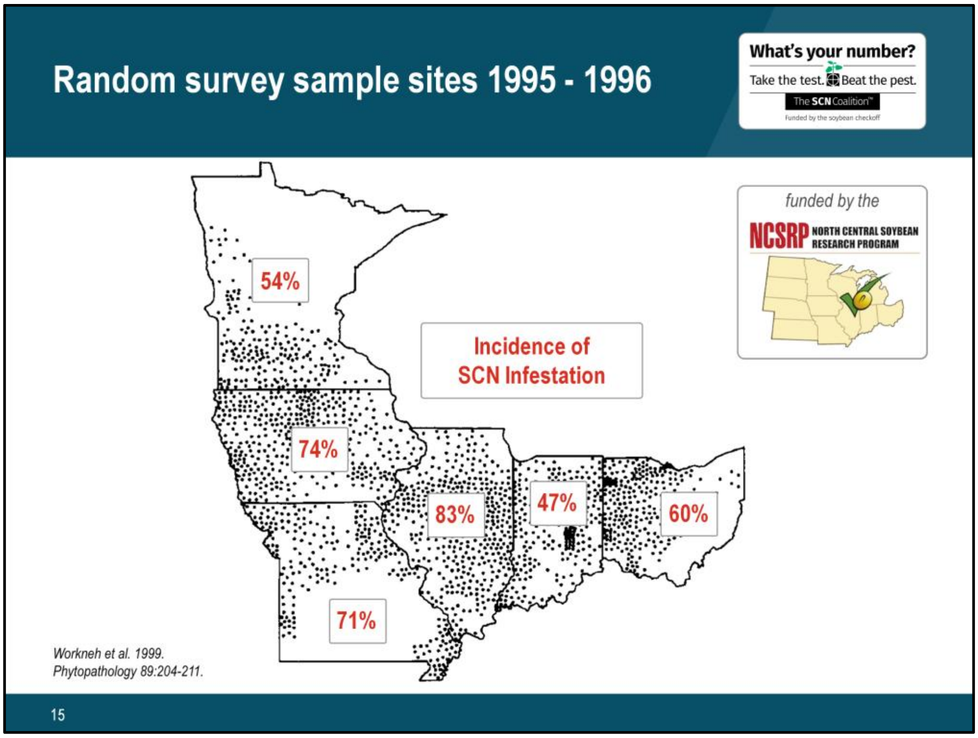
In this map, soybean-producing counties in the U.S. from 2008 to 2013 were underlaid in blue.
The blue counties showing on this map represent soybean-producing counties where SCN hadn't been found as of 2014.
Soybean cyst has now covered 70% to 80% of where soybeans are grown in the United States.



Here's the most recent map, published earlier in 2017. There were 34 new counties found to be infested with SCN between 2014 and 2017. Notable points include:

- **Iowa** added 1 new county to become the second state in the US in which SCN has been found in every county, along with Illinois. Indiana likely will be next.
- SCN was found for first time in one county in **New York**. There is a significant amount of soybeans grown in New York.
- **North Dakota** had the most newly discovered SCN-infested counties, seven, between 2014 and 2017.

Identifying one SCN-infested field in a county puts that county on this map. But it doesn't show how widespread the nematode is in a particular county or state. To do that, an intensive survey is needed.



Researchers collaborated with USDA's National Ag Statistics Service (NASS), which visits randomly selected fields every year to measure corn and soybean growth (to predict yields), to do a **survey for SCN** in 1995-1996.

The NASS personnel pulled a soil sample from every field and sent the samples to be tested for SCN. Nearly 1,400 samples were tested, and the percentages of infested fields in the states were much higher than expected.

A decade later, in the mid 2000s, Iowa State did a random survey of just Iowa with the same USDA NASS personnel, and found SCN in 72% of the sampled fields.

Also in the mid 2000s, Dr. Terry Niblack at the University of Illinois did a random survey of Illinois with USDA NASS, and 82% of the fields were found to be infested with SCN.

It's very interesting that two of the states that did random surveys 10 years later came up with roughly the same percentages.

The random survey of Iowa is currently being re-done in 2017-2018, and with half of the samples processed from 2017, over 60% of the fields are infested with SCN.

SCN is considered the most damaging soybean pathogen in North America

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Pathogen / disease	Allen et al. 2010-2014 estimates – rank in US*	Wrather et al. 2006-2009 estimates – rank in world**
soybean cyst nematode	1	2
sudden death syndrome	2	14
seedling diseases	3	4
Phytophthora stem & root rot	4	8
charcoal rot	5	7
Septoria brown spot	6	3
Sclerotinia stem rot	7	9
brown stem rot	8	15
Fusarium wilt and root rot	9	20
pod and stem blight	10	19

** Allen et al. 2017. Plant Health Progress doi:10.1094/PHP-RS-16-0066*
*** Wrather et al. 2010. Plant Health Progress doi:10.1094/PHP- 2010-0125-01-RS*

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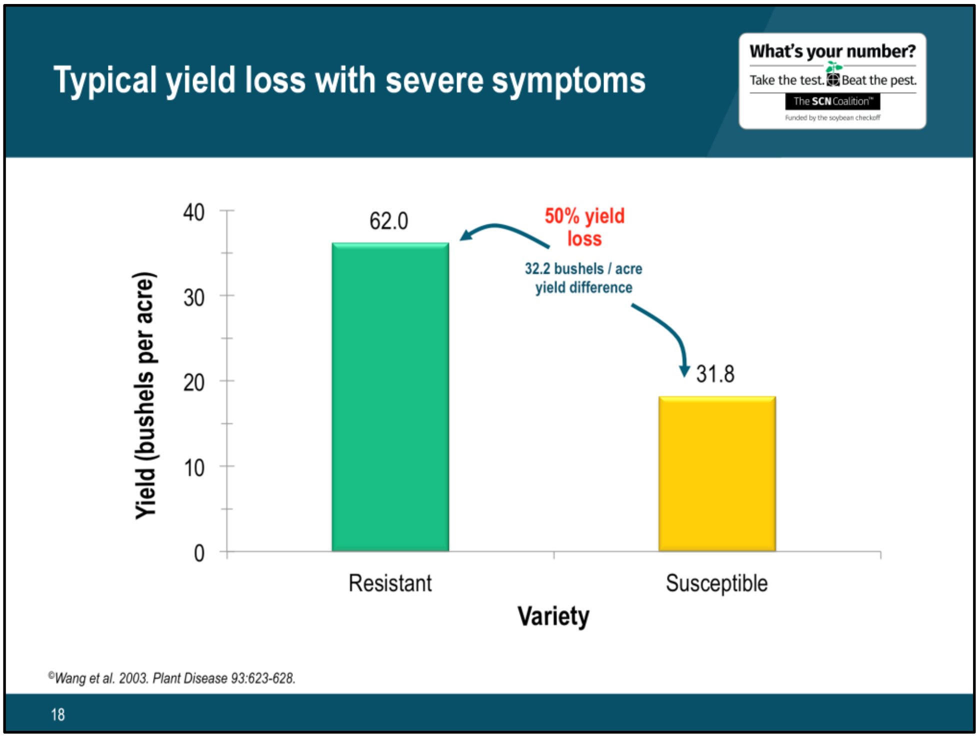
Obviously SCN is very widespread and the damage potential is so great that it is, in almost everyone's opinion, the most damaging soybean pathogen in the United States. A group of plant pathologists rank the most important soybean pathogens and come up with yield loss estimates.
Their most recent report, published in 2017, summarized the yield losses that occurred from 2010-2014. Dr. Tom Allen from Mississippi State University, and 43 others coauthored the paper and published it online. Soybean cyst was No. 1.
Worldwide, a similar group of plant pathologists led by Dr. Allan Wrather, retired from the University of Missouri, ranked and came up with yield loss estimates of soybean pathogens for the world. SCN was No. 2. Soybean rust was No. 1 worldwide. Rust hasn't had the impact in the U.S. that we'd expected.

SCN is certainly the No. 1 soybean pathogen in the minds of many soybean plant pathologists.
And it's because of instances of damage like the one shown in this image. Here's an aerial photo from Central Iowa showing severe SCN damage.
In situations like this, if you grew a resistant and a susceptible soybean, you might get twice the yield out of a resistant variety than a susceptible.

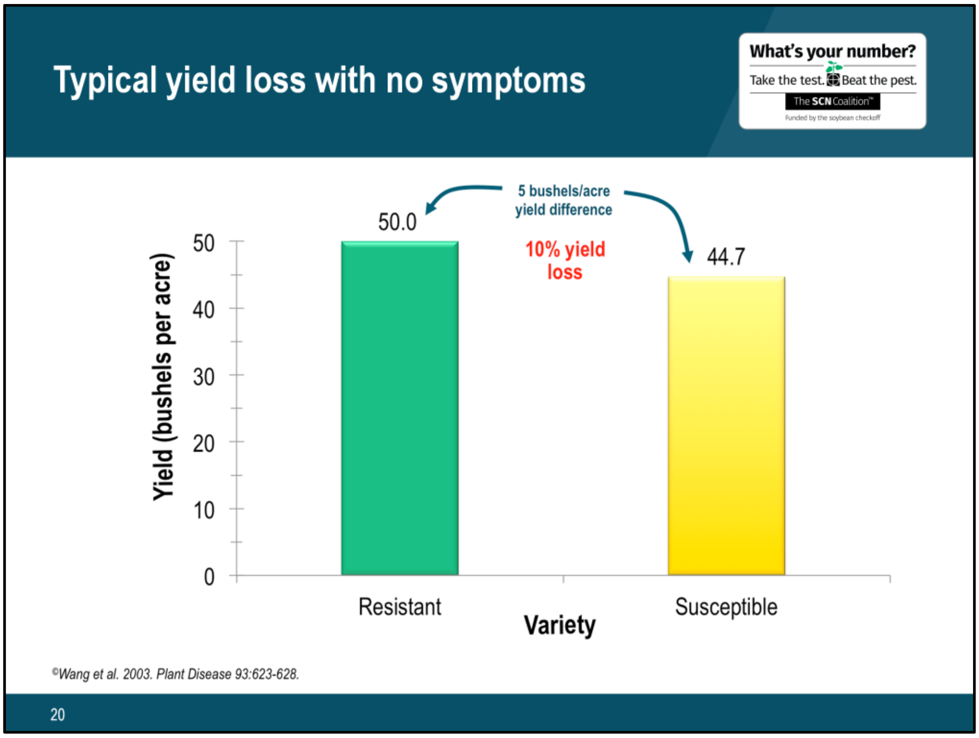


When people ask what level of yield loss is caused by SCN, it can be 50%.

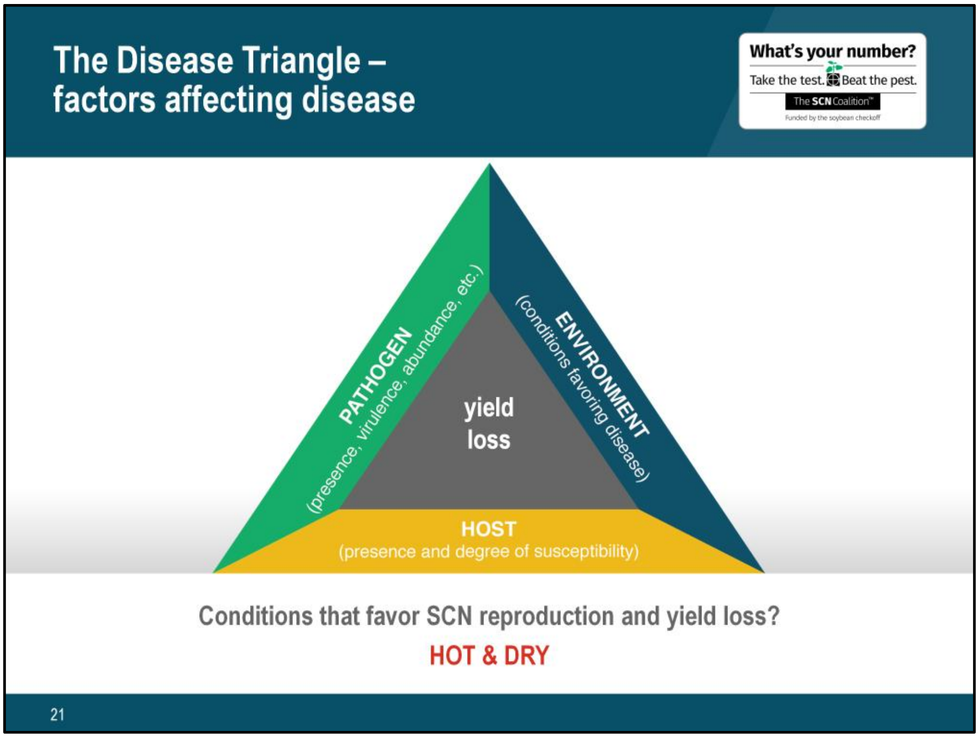
The data on this slide show 50% yield loss. If you didn't grow a resistant variety, you got half the yield of a resistant variety.

In reality, the yield loss is probably much more than 50% because resistant varieties don't yield as well in SCN-infested fields as they do if the nematode isn't present. Even resistant varieties suffer some yield loss, but it certainly yielded double the susceptible.

One of the big problems in Midwest is: This is what SCN infested fields look like. You see beautiful, lush green plants.
In this scenario, you might only get a 5 bushel per acre difference between susceptible and resistant varieties.



Some might say 5 bushels per acre is hardly worth worrying about – but that's a 10% yield loss. So SCN is extracting a toll whether the damage is obvious above ground or not.



The severity of the SCN situation depends on the nematode, weather conditions, and the soybean variety.
Plant pathologists wrap these three factors into what they call the "disease triangle." This is plant pathology 101.
The amount of disease that occurs depends on how aggressive the pathogen is, how susceptible or vulnerable the host is, and how conducive the conditions are.
That disease triangle concept works really well to explain **yield loss** from SCN. The **conditions** that favor SCN reproduction and yield loss? **hot and dry**.
Soybean cyst nematode reproduction is very high and yield loss is extreme in hot and dry conditions.

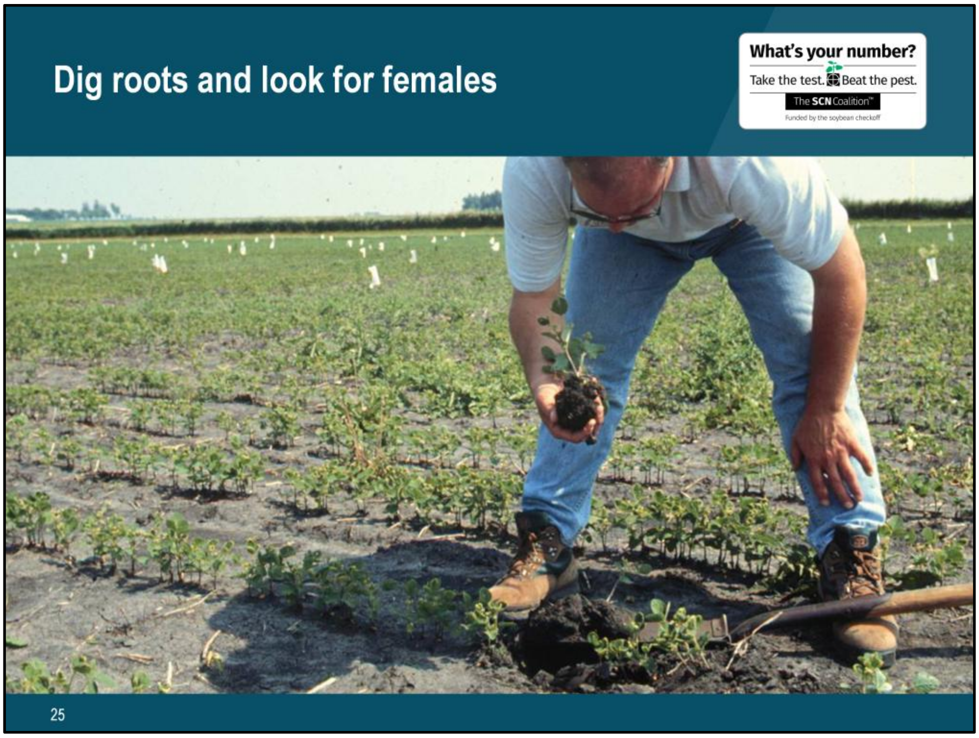
But whether it is the situation shown on the left or the right, underground, **SCN** is **churning away**.
It's building up numbers. And the higher the numbers, the greater the yield loss.

How would you know if you have soybean cyst nematode when fields look like this?

It's a psychological challenge to convince someone to think about looking for what's going wrong in this field when the beans look so good.

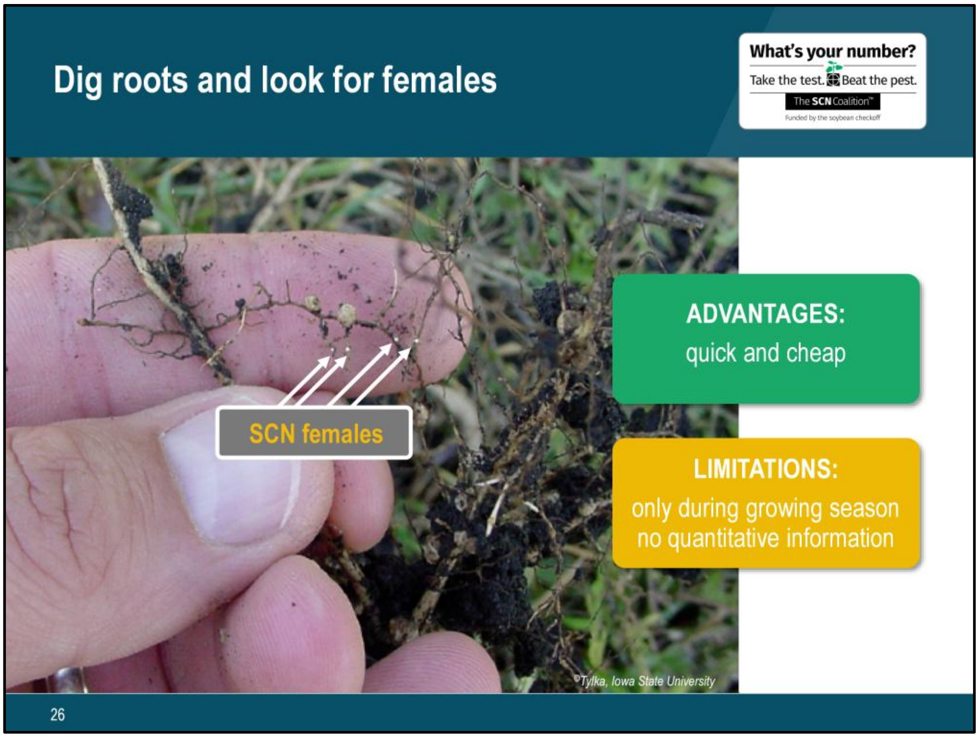
There are two ways to effectively scout for soybean cyst nematode.
Neither involves driving in an air-conditioned pickup truck at 75 miles an hour.
So you have to stop the pickup truck and do one of two things:

- Dig roots and look for females on the roots.
- Collect soil samples.



If you're digging roots and looking for females, the most important word is "digging" - as opposed to "pulling" roots. You need to take a trowel or shovel and pop out a clump of plants. You can do this as early as 5-6 weeks after planting through the month of July into early August.

The drawback of this scouting method is that later into the season, new, white SCN females are forming on young roots, and in August, those roots are 3 feet or more deep and hard to get at when you dig with a shovel.

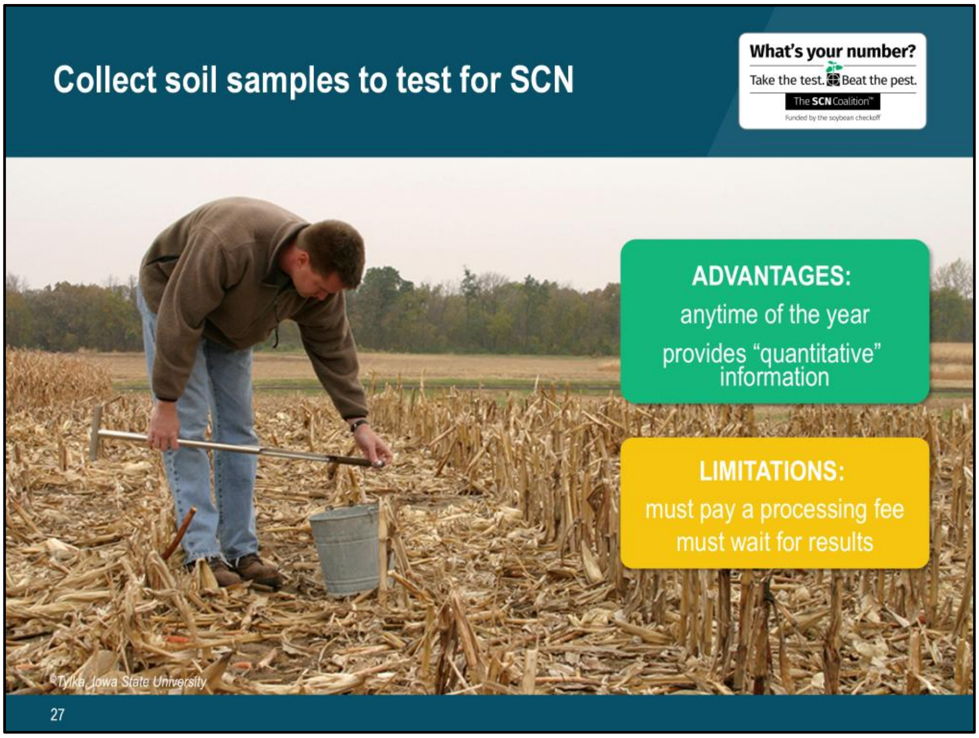


You dig roots, shake the soil off and look for little white females.

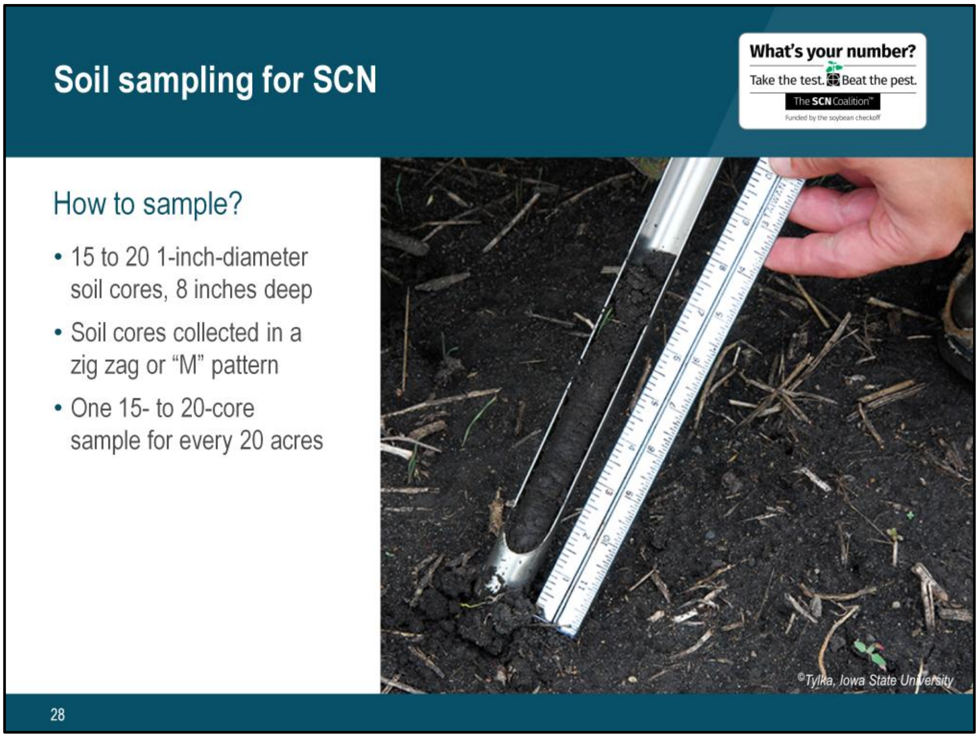
The advantages of this type of scouting: it's quick and cheap. In fact, it's free – you don't have to pay anyone to look.

But there are limitations: You can only do this method starting about 6 weeks after planting through the month of July, maybe into early August. And secondly, you don't get quantitative information.

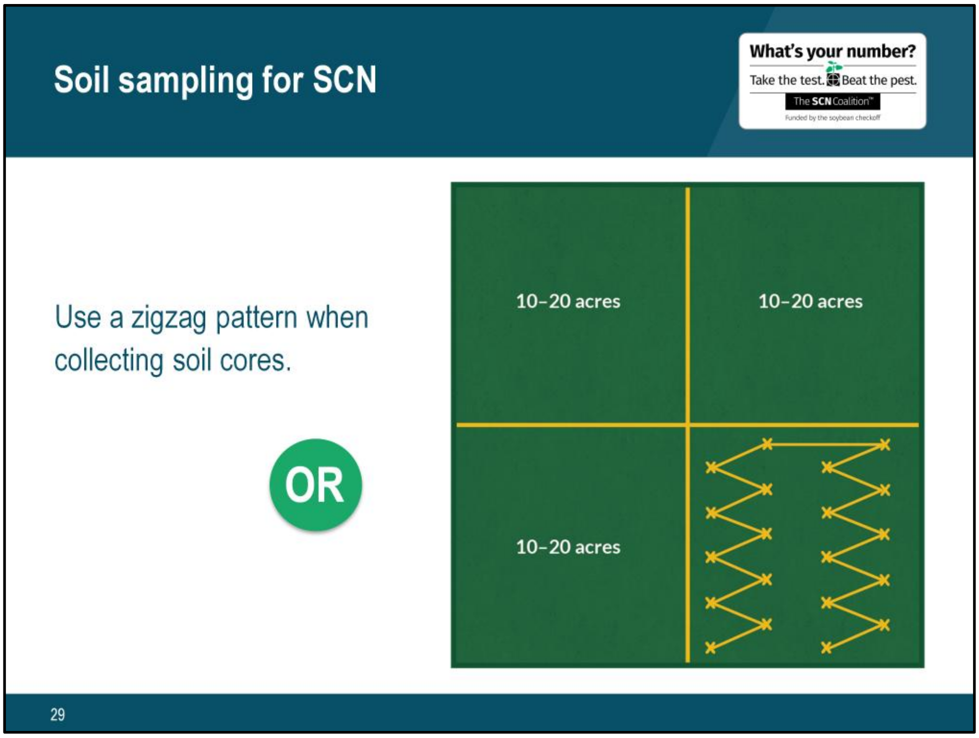
In this photo, you see 4-5 females on the root which could lead you to think the numbers are relatively low. But you could come back a week later and see 10 times as many females on this same root, because the females pop out somewhat in cycles through the season.



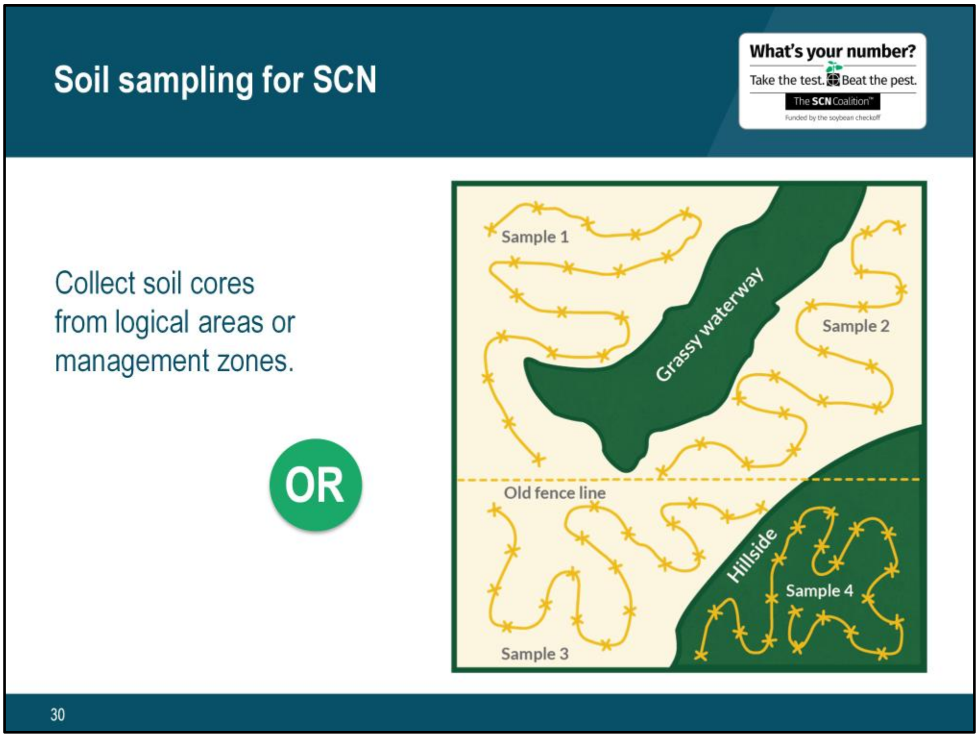
The other way to check a field is to collect soil samples. That's really easy to do, as well.
This method is great because you can do it any time of year, and you get "quantitative" information.
Note that the word quantitative is in quotation marks on the slide. We'll talk about that in a minute.
The limitations of this scouting method are: 1) you have to pay for someone to process that sample, and 2) you have to wait for the results to come in.
But it's perfectly fine to do this as a way of scouting.



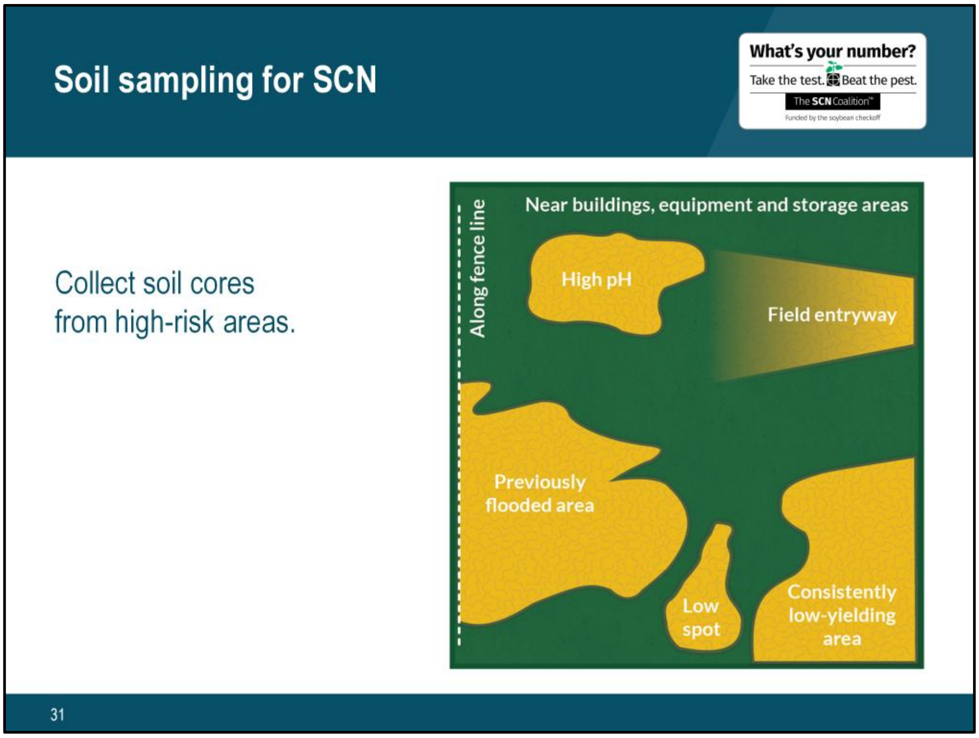
How should you sample? It's pretty straightforward: We need soil cores. We'd like 20 cores or more, to a depth of 8 inches. You'll want to collect the cores from many different places in a field. Use a zig-zag or "M" pattern through the area.
We'd like 20 or more core samples for every 20 acres or so. That's a pretty intensive sampling program in some respects, but that's because the nematode is so aggregated in the field.



If you have an 80-acre field, you could divide it into four 20-acre parcels and then zigzag your way through and collect 20 core samples from each one of those parcels. **Or…**



There can be more effective ways to approach sampling than dividing a field up into equal, rectangular areas. For instance, you can think of the field in terms of management zones or areas. You might take four separate samples based on an agronomic feature in that field. That's fine as well. **Or…**

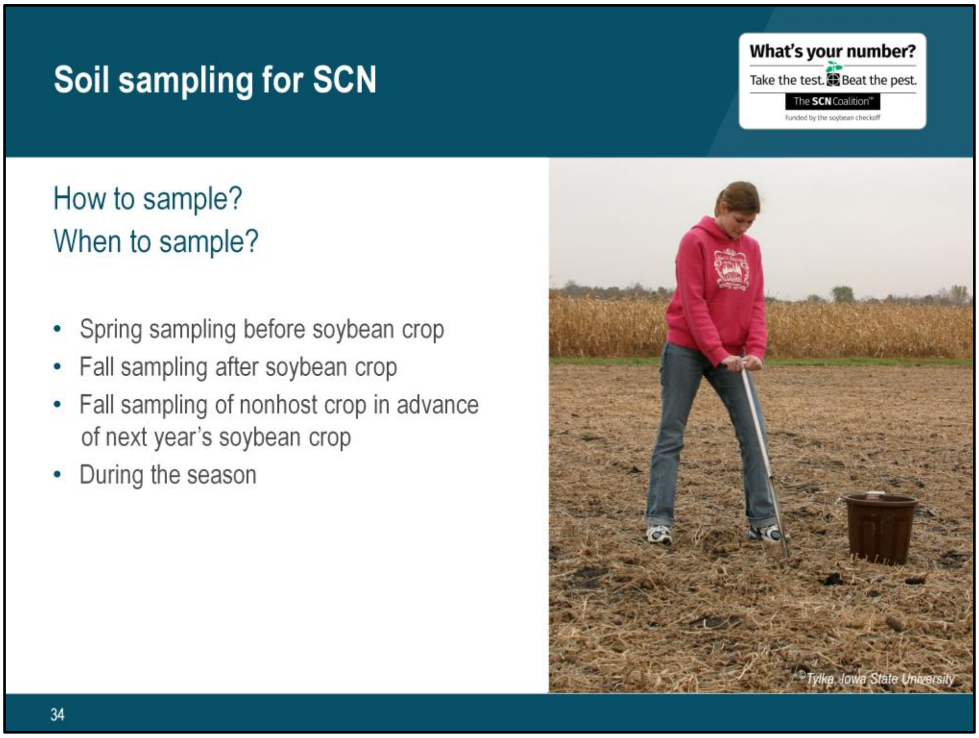


Another approach is to target sampling efforts to high-risk areas where SCN might first be found in a field. You could collect soil cores from:

- The field entryway, where soil falls off implements as they're moving from one field to the next.
- High pH areas, because SCN loves high pH soil.
- Areas of the field where you just can't figure out why yields are consistently low.
- Low spots and previously flooded areas where surface water might move soil from surrounding areas.
- Along the fence line. This is quirky, but some nematologists have reported seeing a strip of yellow plants along fence lines. The hypothesis is that windblown soil infested with SCN hits the fence line and falls there.

Ultimately it's about taking soil cores, mixing them up really well, and then pouring that mixed soil into a soil sample bag and sending it to a lab.

Not to belabor this point, but the cores need to be mixed up really well.
There shouldn't be intact cores in the soil bag.

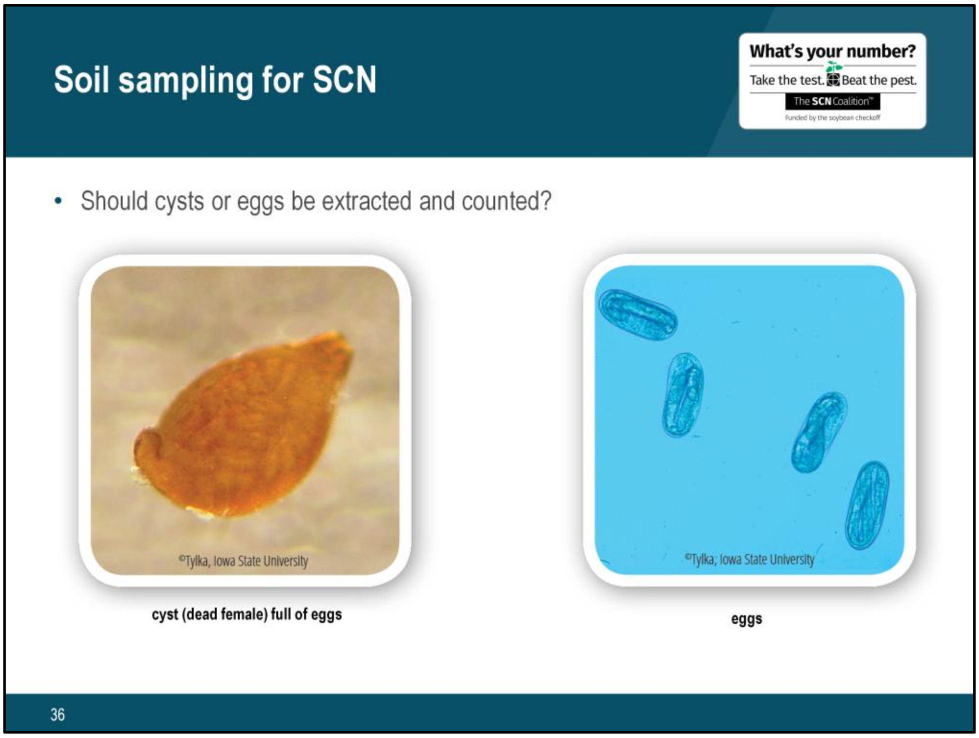


When should you sample for SCN? That's flexible.
You can sample when you want to. That can be:

- In the spring before planting, if you're worried about it.
- In the fall, if you're wondering why the yield was so low.
- Or you can sample corn stalks in the fall getting ready for soybeans to be grown the following year.

That's an ideal time to sample: fall sampling of fields that will have soybeans grown the following year.
You can even sample during the season.

There's also nothing wrong with pulling soil cores from the root zone of the soybean crop in the middle of the season.



What should you look to be extracted and counted when you send in your soil samples? Cysts or eggs?

Not many labs offer both of these options. Most will offer one or another. It varies somewhat by geography or state.

There are certain states where the trend is that they do cyst counts. There are other states where the laboratories – both public and private -- do egg counts.

Just be aware: a cyst can contain hundreds of eggs. Whereas with egg counts, they take the extra step and break the cyst into individual eggs.

Both types of counts are fine if you want to test a field to find out whether SCN is present or not.

Egg counts give more precise information than cyst counts, because the cysts are broken open to count the eggs.

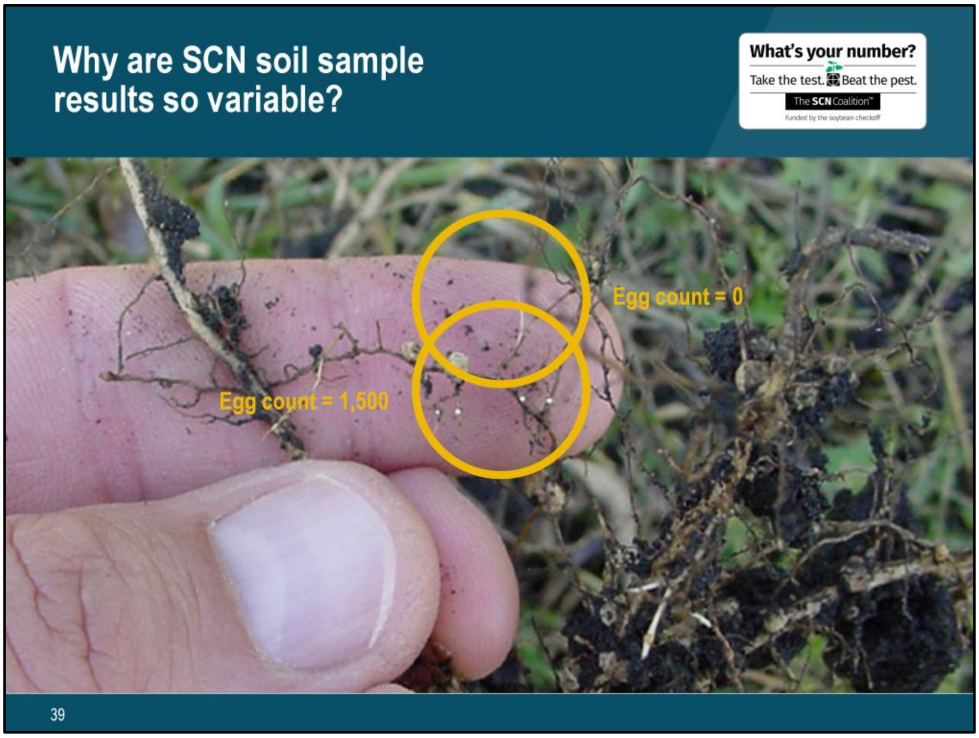
When a cyst is counted, it could be an old cyst that only has 20 eggs left in it, or it could be a new cyst with 200+ eggs. Cyst counts are less precise than egg counts.

But **cyst counts** are cheaper than egg counts because it's one less step.

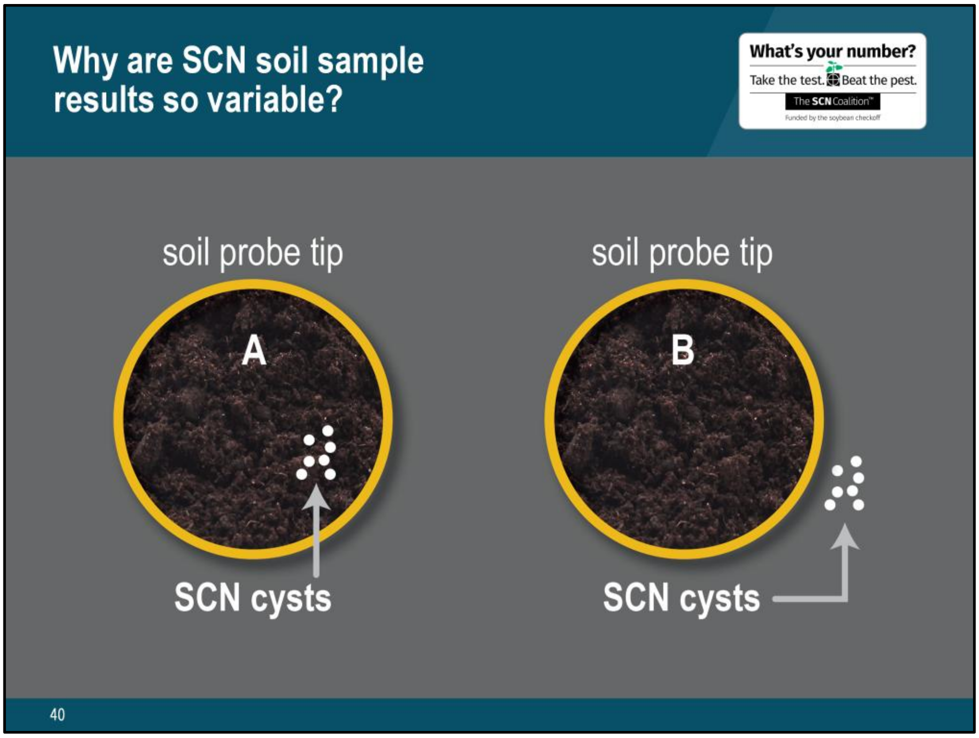
SCN research is almost always done with egg counts. So if you want to read research and apply it to a particular farmer's field, it would be easier to do with egg counts.

There's no right or wrong answer. Just be aware that some labs do cyst counts and some do egg counts. And there could be labs that offer both.

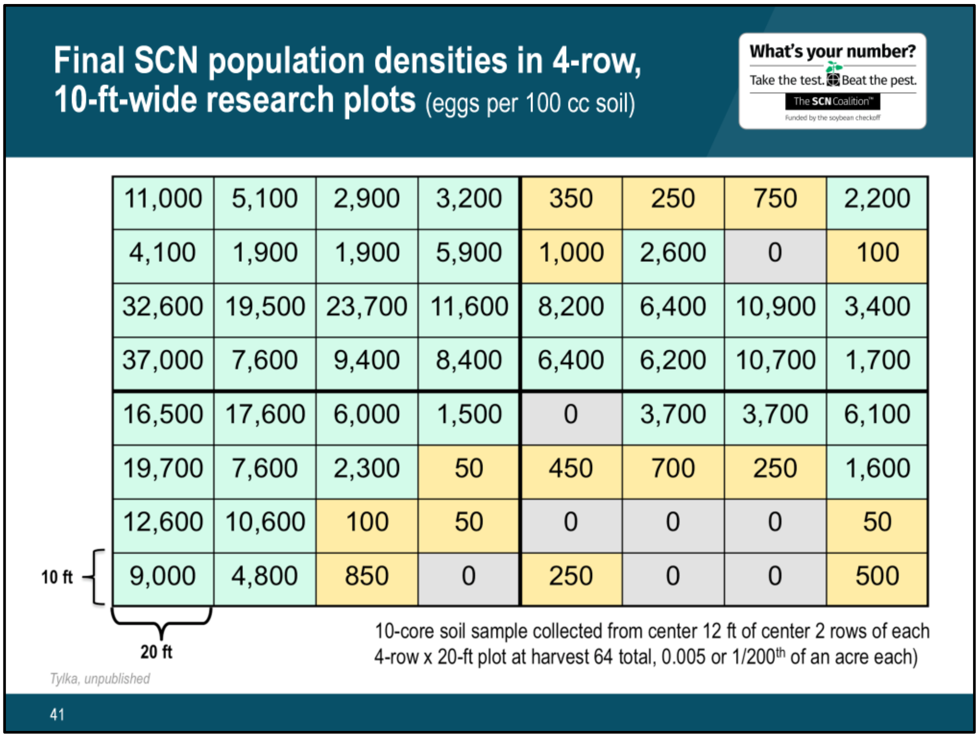
I’d also like to touch on variability of results.
You’ll never encounter any situation with data that is more variable than SCN egg numbers.
SCN egg counts in particular are extremely variable.



The reason why is shown here. This gives you a feel for how big the females are – they're visible with the naked eye.
This yellow circle is the size of the tip of a soil probe. So imagine if that root was growing in the soil and we put the probe right there, we'd capture five females. If the soil probe was placed ½-inch away, five females full of 200 to 250 eggs each would have been missed.



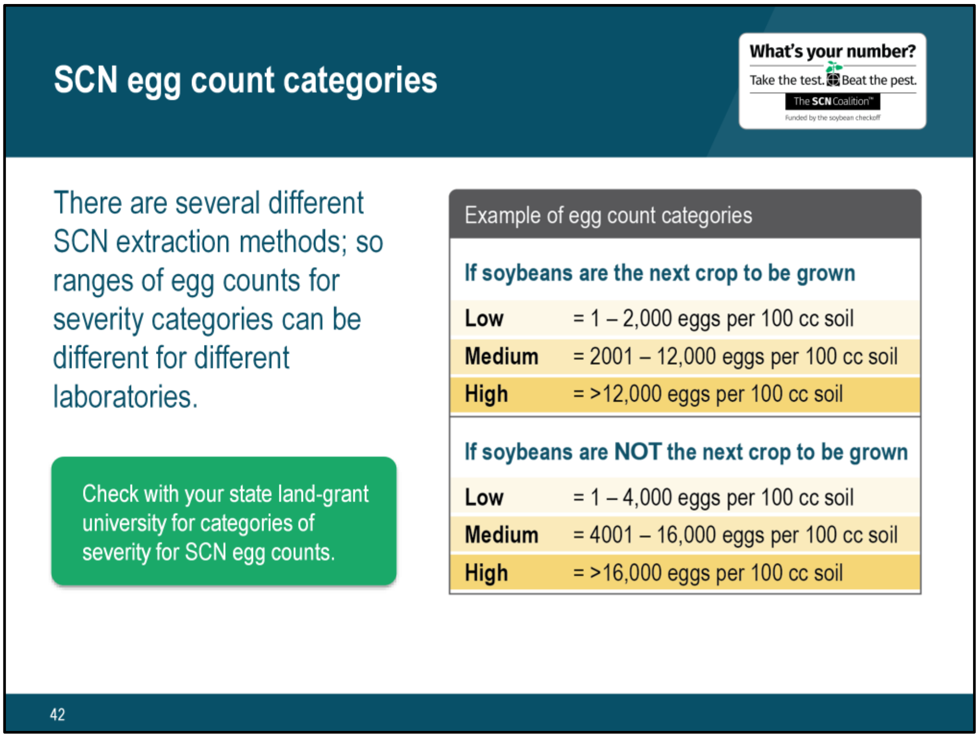
This graphic represents that situation.
The probe tip A collects seven cysts. Probe tip B is ½-inch away and misses those. And that's not plus-or-minus seven objects if you're dealing with egg counts, it's plus-or-minus 1,500 eggs. So ½-inch gives you 1,500-egg variability.



11,000	5,100	2,900	3,200	350	250	750	2,200
4,100	1,900	1,900	5,900	1,000	2,600	0	100
32,600	19,500	23,700	11,600	8,200	6,400	10,900	3,400
37,000	7,600	9,400	8,400	6,400	6,200	10,700	1,700
16,500	17,600	6,000	1,500	0	3,700	3,700	6,100
19,700	7,600	2,300	50	450	700	250	1,600
12,600	10,600	100	50	0	0	0	50
9,000	4,800	850	0	250	0	0	500

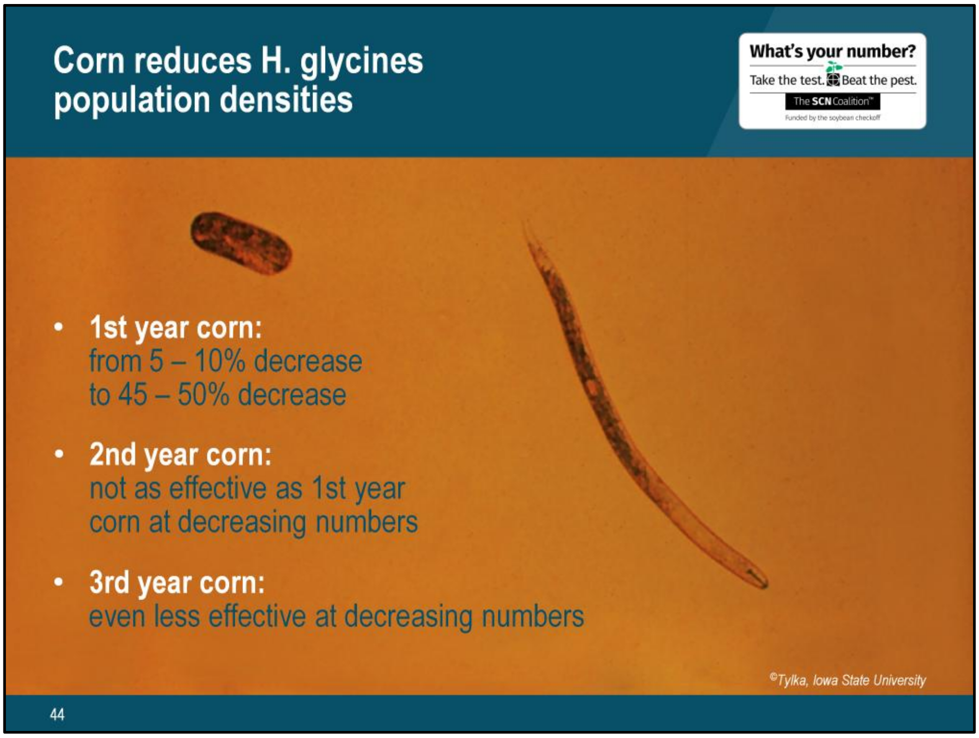
To illustrate this variability, here's a map of some research done with susceptible soybeans many years ago. The research plots were small, 4-rows wide by 20-foot long. So each rectangle on the map represents 1/200 of an acre. Researchers collected a 20-core soil sample from each one of those 10-foot by 20-foot plots. Shown on the map are end-of-season egg counts from the plots. In the top right, there were zero eggs in a sample collected 10 feet away from a sample with 10,900 eggs.

This large amount of variability is easy to understand when considering what was just illustrated in the previous slide. Also, this map shows some pretty high egg counts that can happen in real fields: 23,000, 32,000, 37,000 per 100 cc of soil.

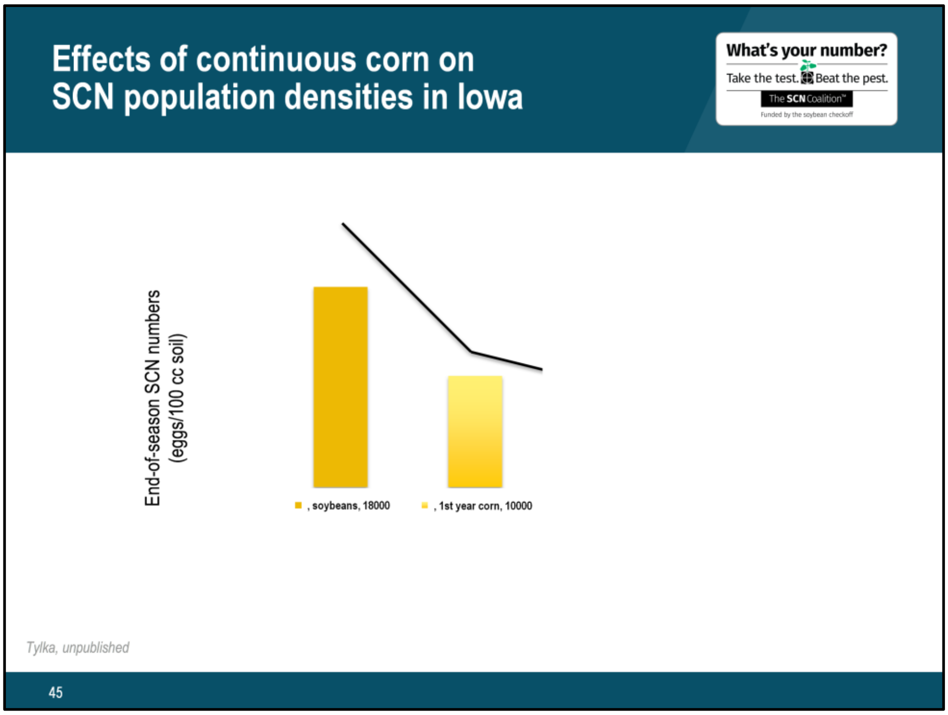


One last point on egg counts: It's human nature to want to know if an egg count form a sample is low, medium or high when you get results back.
There are several different ways that labs extract SCN, and the egg counts will vary depending on the method.
Shown is one example of a range of egg counts and how they match up to low, medium or high damage potential.
If soybeans are going to be the next crop grown, anything below 2,000 is considered low, 2,000 to 12,000 is medium, and more than that is considered high.
If soybeans will not be the next crop grown – if corn or some other nonhost will be grown –SCN numbers will drop, and the low/medium/high numbers are increased.
These egg numbers for damage categories will not be applicable to all states or areas. <u>ALWAYS check with the land grant university or lab that processed the sample.</u>

Now let's discuss how to manage SCN.
We know that when you grow a year of a non-host crop – the numbers will drop.
We don't want anyone growing continuous soybeans.



Here's what happens when a year of corn is grown in Iowa.
Remember that juvenile worms hatch from SCN eggs and that the hatched juveniles are the "weak link" in the life cycle. If a juvenile hatches in this year's corn crop, there's no way it can survive to next year's soybean crop.
In Iowa, it has been observed that one year of corn can drop SCN egg numbers anywhere from 5 to 50%.
A lot of folks see this and think, "I'll just grow 2-3 years of corn and really knock it back." Unfortunately that doesn't work – it's not a linear relationship.
The second-year corn is not as effective as the first-year corn at reducing SCN egg numbers. And third-year corn is even less effective.



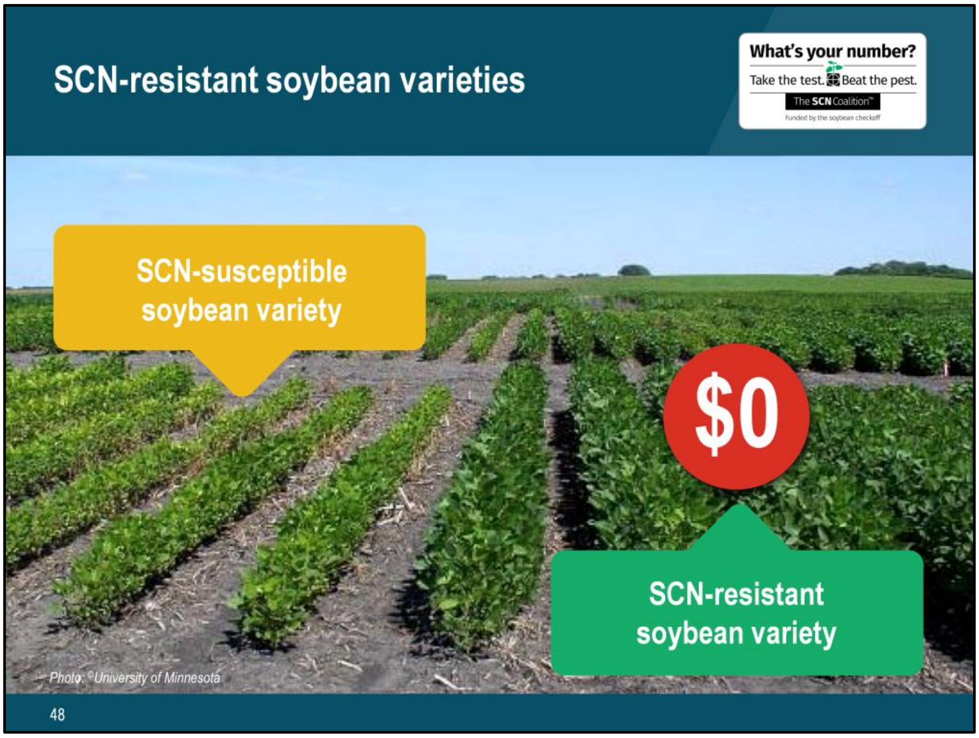
That pattern is illustrated in this graph, showing end-of-season egg counts after various crops.
In the yellow bar we see a soybean crop leaving behind 18,000 eggs per 100 CCs of soil.
One year of corn can drop that down to 9,000 or 10,000.
But if you grew a **second year** of corn, that drop won't be as much.
After the **third year** of corn, the slope of the decrease really starts to flatten out.

What we think is happening goes back to the biology of the eggs within SCN cysts. The eggs inside cysts seem to have one of three different types of hatching behavior:

- Some are constitutive – they hatch when it's warm and moist, so they'll hatch in a year when corn or sunflower or whatever is grown.
- Some are inducible – they're only going to hatch when they sense chemicals given off by host roots.
- Some are dormant eggs – these are the eggs that are able to live in soil with no plants being grown for decades.

What we think is, most of the constitutive eggs hatch in year 1 of corn because it's warm and moist enough. More hatching will occur in year 2. And there's not many constitutive-hatching eggs left in the soil after a couple years of corn - only eggs that are inducible that are waiting to sense exudates (chemicals given off by soybean roots) or eggs that are dormant. Nonetheless, let's not disregard the benefits of one year or two years of a non-host crop knocking numbers down.

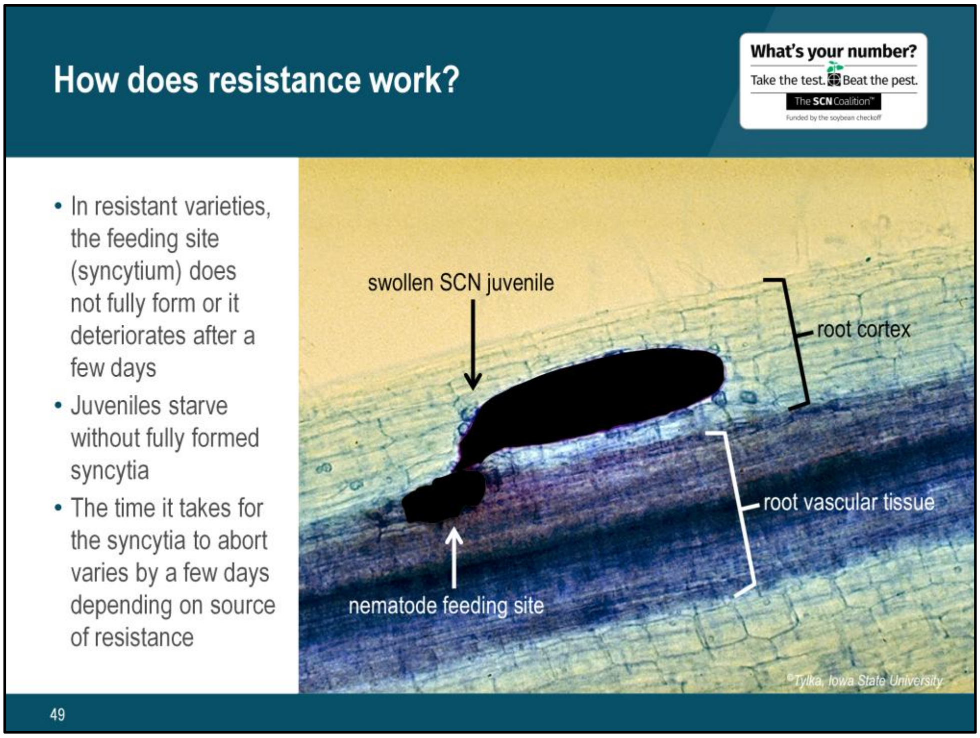
The next management tactic has been a great one. I don't think we'd still be growing soybeans if we didn't have SCN-resistant soybean varieties.



It's literally almost black & white. Or in this photo, dark green versus pale green. You see a **susceptible variety** on the left, and a resistant variety on the right.

The bargain of the century here is that the seed of a resistant variety doesn't cost any more than the seed of a susceptible variety – it's **free**.

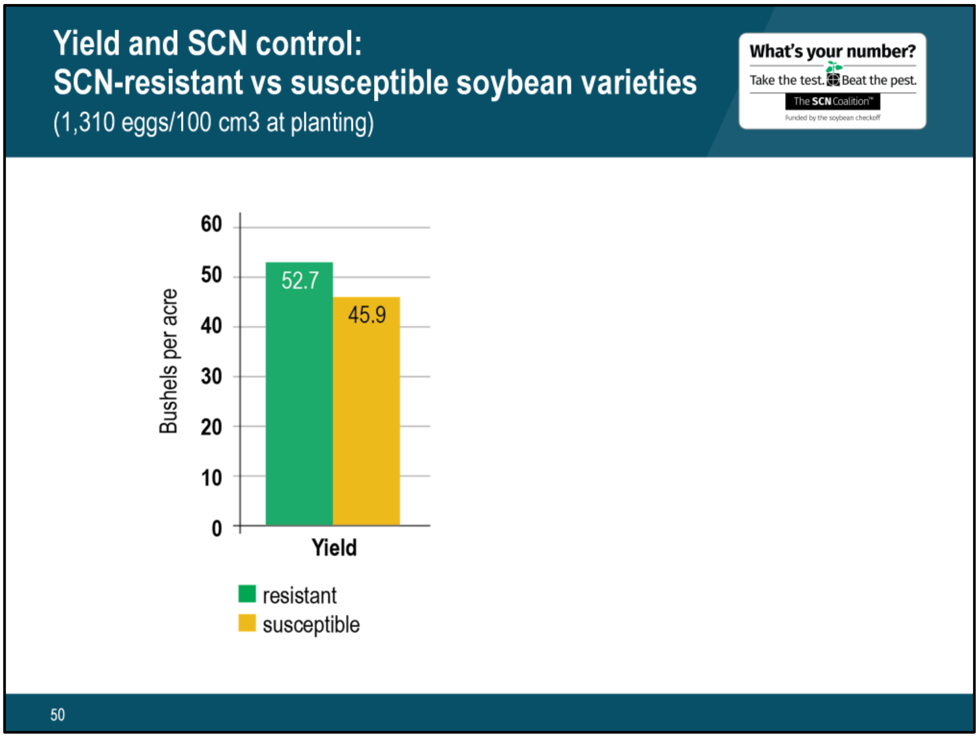
This has been a wonderful thing: the free protection we get from SCN-resistant soybeans. But it may turn out to be a fatal flaw.



How do resistant soybean varieties control SCN? Let's go back to photo of the swollen juvenile in the root. In **resistant varieties**, the feeding site either doesn't form at all or it dies after a few days. And the nematode can't complete its life without that feeding site. So the nematode **juveniles starve** inside roots of the resistant varieties. The worms still go in but they're either unable to feed or they feed for a day or two and then die off.

The **time it takes** for this dying off of the feeding site to happen can vary a little bit depending on what type of resistance the soybean variety has.

But the mechanism is ultimately the same. Worms go in, they try to set up a feeding site and it doesn't happen.



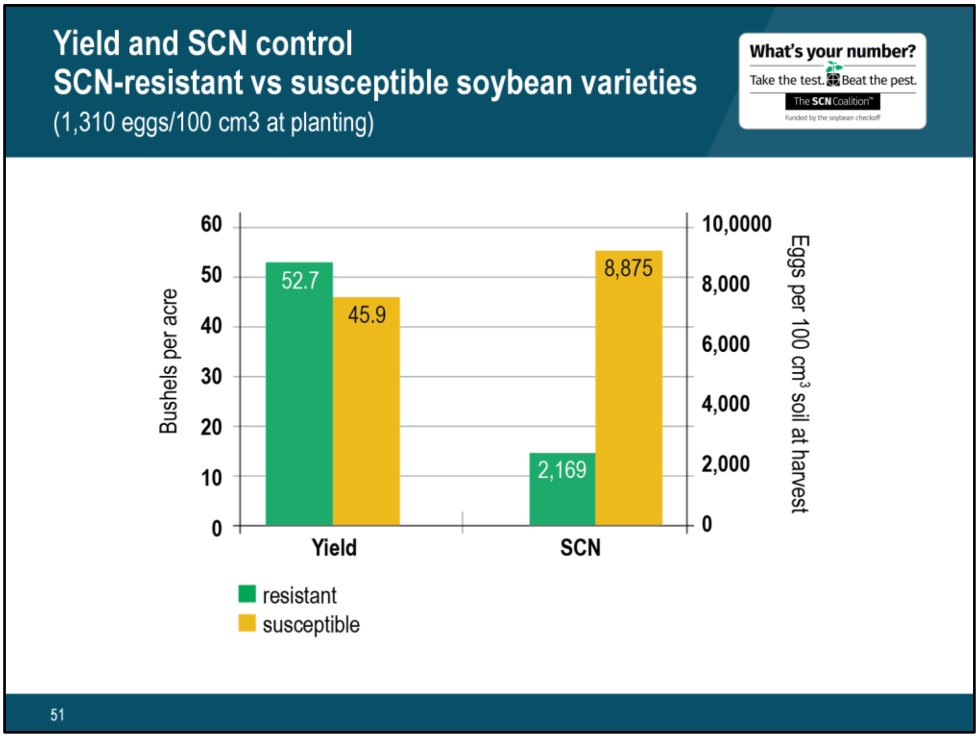
I tell farmers that resistant soybean varieties pay them twice. The first payment is in yield.

Here are some yield data from resistant vs. susceptible soybean varieties.

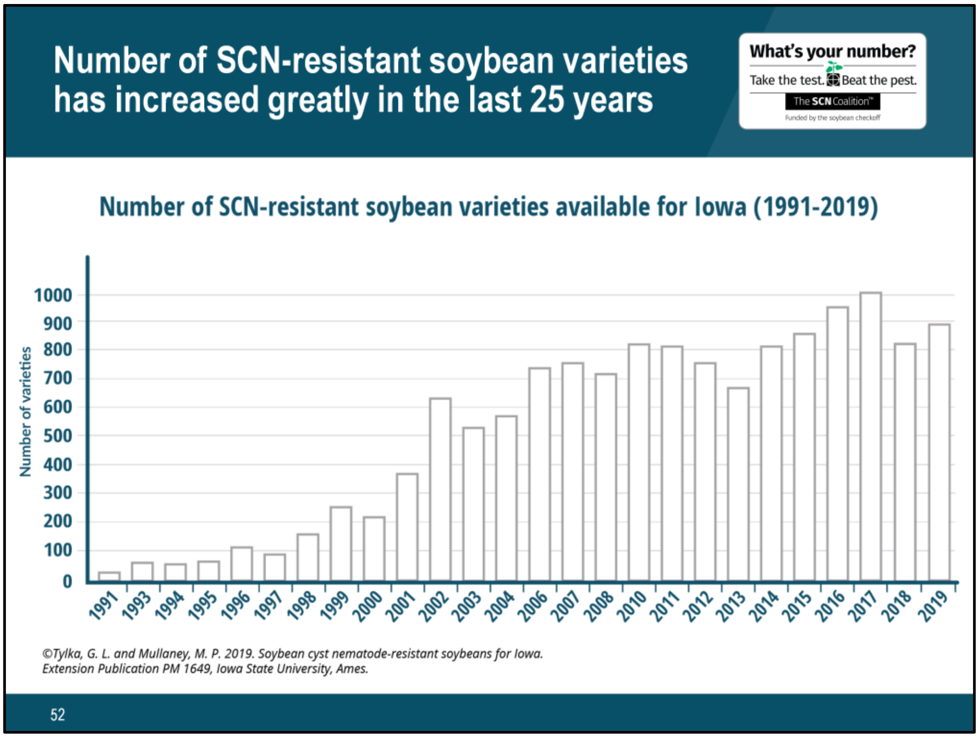
The green bar is an average yield of about 60 different SCN-resistant varieties grown in an SCN-infested field. The yellow bar is the average of four widely grown susceptible varieties also grown in the field.

In a typical Midwest field, we can see these types of yields, 46 bushels per acre vs. 53 bushels per acre.

That's 7 extra bushels per acre – that's money in the bank – and that's the first payment.



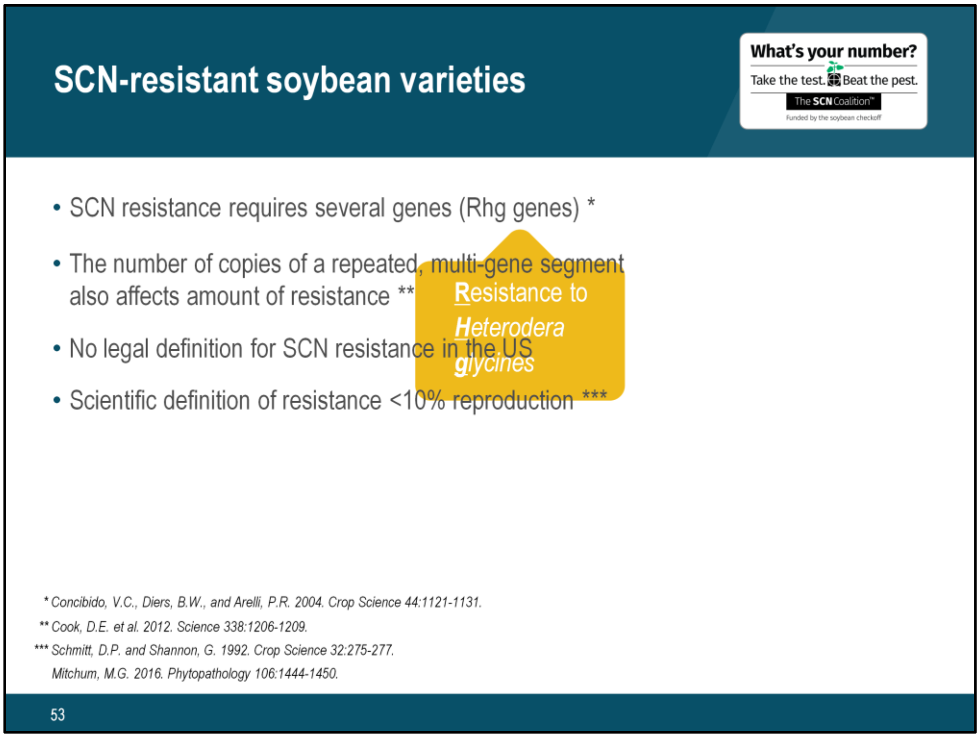
But there's a second payment that the farmer will receive a couple years down the line: that's from the nematode control.
In the 2 bars on the right in the graph, the green bar is the end-of-season egg count left behind after the resistant soybeans that yielded 7 bushels more, and the yellow bar is the egg count left behind under the susceptible variety.
We started out with about 1,300 eggs per 100 cc of soil in this particular field and 1,300 vs. 2,100 is almost a wash when you consider variability in egg counts. But clearly, egg counts increased five- to six-fold under the susceptible soybeans, which gave the farmer 7 bushels per acre less.
These higher egg counts are going to ding soybean yields the next time soybeans are grown in this field.
So the lack of eggs left behind under the resistant variety is the second payment.



This is a graph showing the number of resistant varieties available for Iowa farmers since 1991.
There were 29 varieties available in 1991 and 1,002 in 2017. In 2018, there were 820. That's fewer because of industry consolidation. In 2019, there were 891 varieties available.

The availability of SCN-resistant varieties has been a remarkable success story.

{NOTE: The 891 "varieties" in 2019 are not 891 unique sets of genetics. Some companies develop soybean varieties and sell them to many different seed companies, who sell them to farmers under different names. Still - there are many hundred genetically different varieties available.}

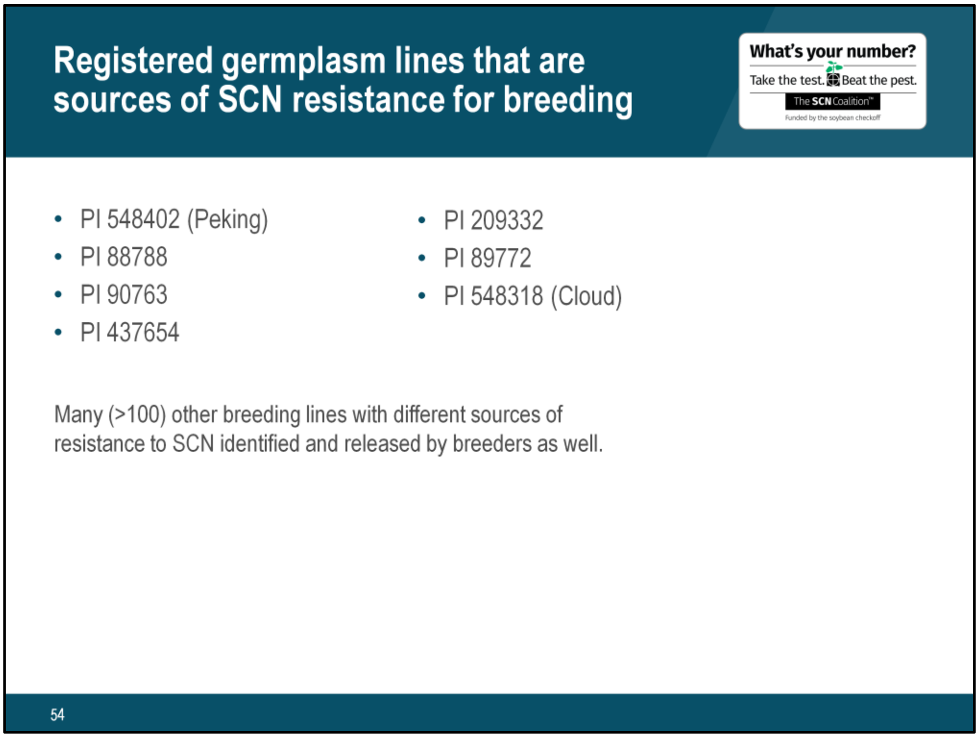


A couple of points about the biology of SCN resistance:

- Soybeans are resistant by containing several resistance genes, so it's not a single gene resistance, like Phytophthora resistance and Rps1k genes.
- The SCN resistance genes are called R*hg* genes, which stands for Resistance to *Heterodera glycines* – which is the scientific name for soybean cyst nematode.
- **A paper** published in 2012 showed that it was not just the presence of resistance genes – but also the number of copies of the set of genes – that determine how resistant a variety is.

There's no **legal definition** of a resistant soybean variety in the United States. There are standards in Canada.

There is a **scientific definition** that we all abide by - a resistant variety should allow less than 10% reproduction relative to a susceptible variety. In other words, there should be 90% suppression or control.



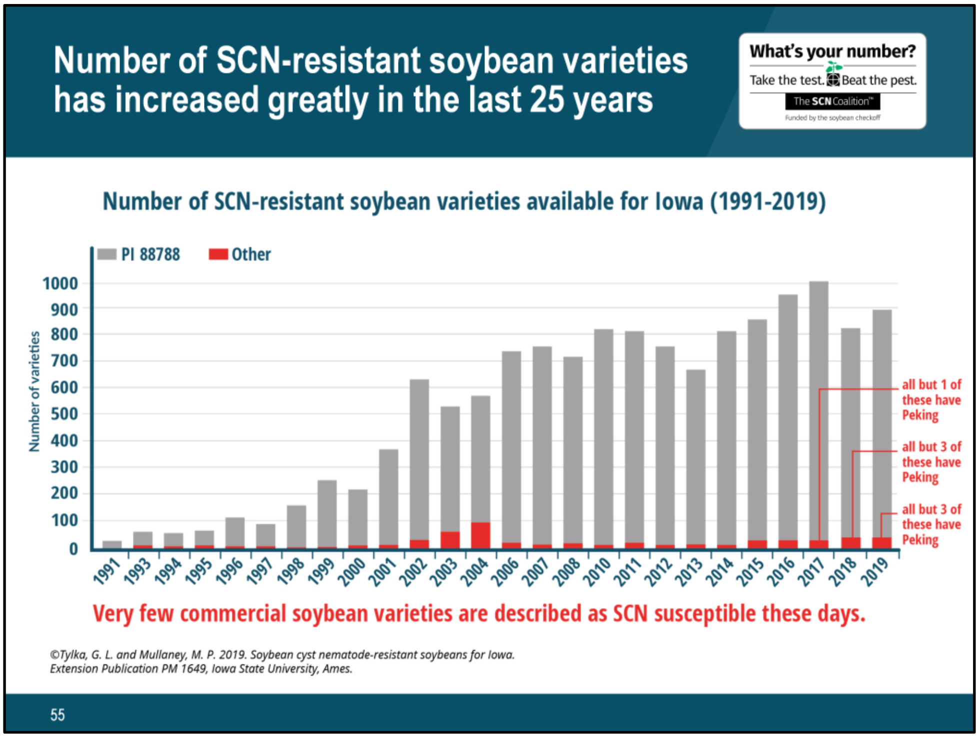
When considering resistant soybean varieties, the concept of "sources of resistance" quickly comes into play – sources of resistance are breeding lines that plant breeders use to introduce resistance genes into really good agronomic soybean varieties.

Imagine you have a great variety that yields 75 bushels per acre in non-nematode fields, and you want to make it resistant to SCN: You have to cross it with one of these breeding lines.

There are 7 main breeding lines, but there are hundreds of others that plant geneticists and breeders have identified.

In simple terms, pollen from one plant is introduced into the flower of another plant – and the offspring are tested to see whether they:

- retained the good agronomic, high yield characteristics
- have been made resistant to SCN



Remember the bar graph of the number of resistant varieties available in Iowa from 1991 to 2019?

This version of the graph shows the sources of resistance used in those varieties. Notice that each bar is mainly one color – grey – which is the PI 88788 source of resistance. Very few varieties have any of the other six main sources of resistance or the hundred or more others that are known.

The reason for this trend has something to do with “yield ability.” When SCN resistance genes are transferred into a good agronomic bean, somehow there’s “yield drag” or a lowering of yield potential that results. It is difficult to get both good SCN resistance and high agronomics in a soybean variety using any source of resistance other than PI 88788. Thus, 97% of soybean varieties that Iowa farmers can pick from have PI 88788 SCN resistance.

Can you image what would happen to weed populations if a single herbicide active ingredient was used over and over for 25+ years? The exact same thing happens with extended use of SCN resistance genes.

To complicate things further, very few soybean varieties brought to market these days don’t have PI 88788 resistance. It’s a trait that is almost automatic in the background of new soybean varieties. All the breeding, all the varieties that soybean breeding programs use to improve upon already have the PI 88788 resistance source.

The HG type test measures SCN reproduction on the sources of SCN resistance for breeding

- PI 548402 (Peking)
- PI 88788
- PI 90763
- PI 437654
- PI 209332
- PI 89772
- PI 548318 (Cloud)

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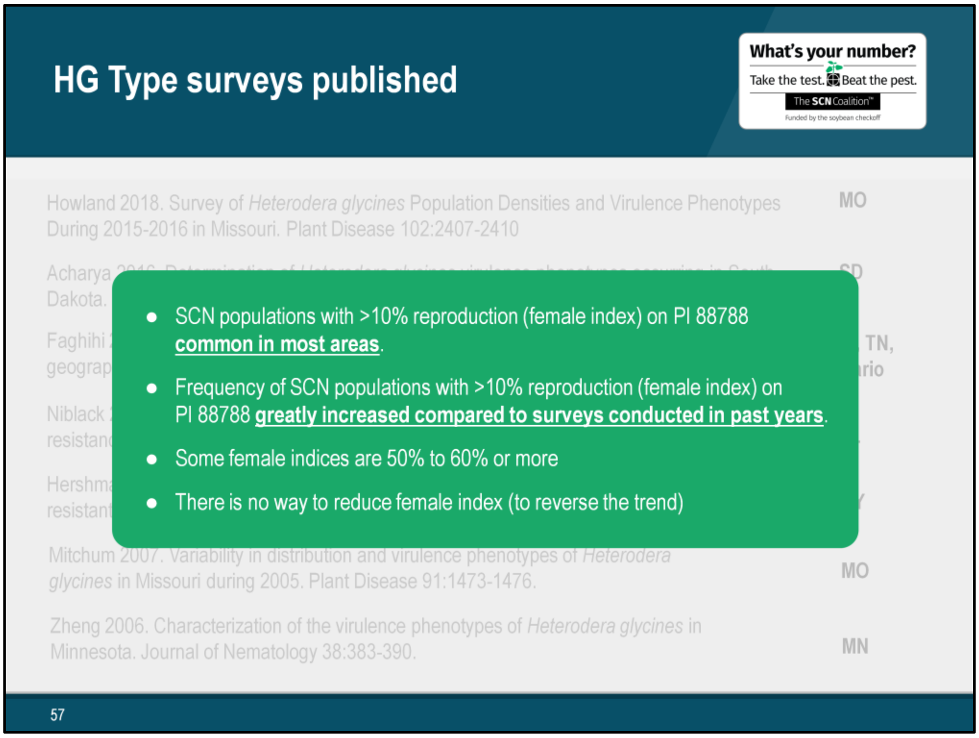
There's a test, called the HG type test, that can be done on the SCN populations in farmers' fields to determine how well the nematodes reproduce on the seven main sources of resistance.
A farmer collects a two-gallon soil sample – an HG type test needs that much soil – and an SCN testing lab will grow all these different sources of resistance in that soil to see how well the farmer's nematode will reproduce on these different sources of resistance.
A lot of nematologists, plant pathologists, and agronomists are doing this to get a feel for what's going on out there in the countryside.



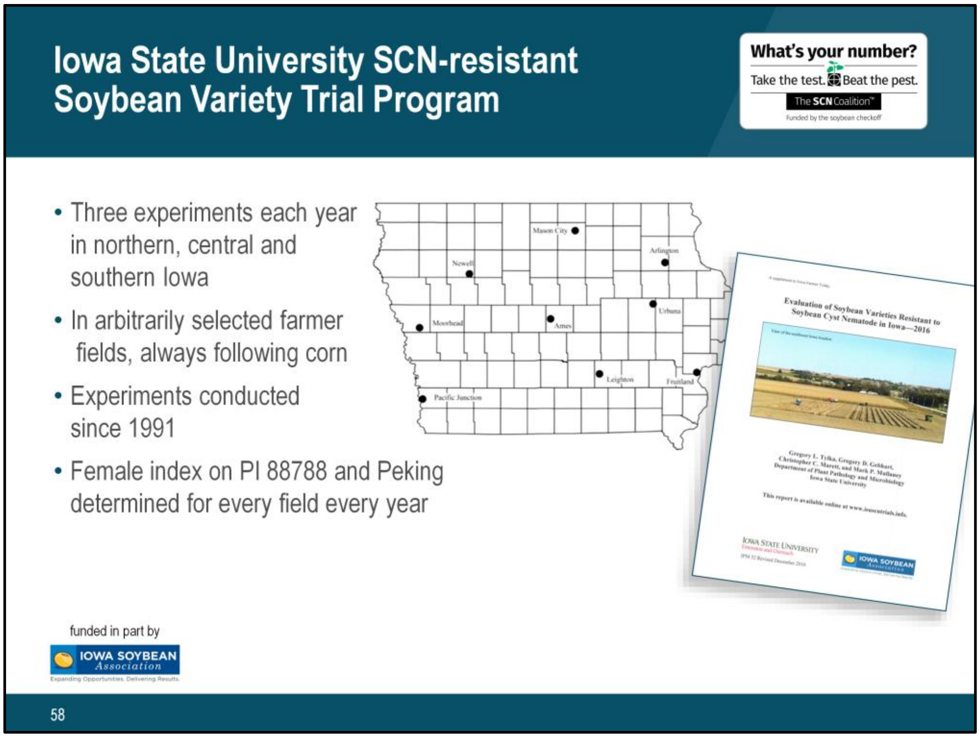
Here are several publications from researchers who've done HG type surveys in their states. SCN populations were collected from fields in the states and then tested on the seven sources of resistance.

Most survey results reveal that SCN populations with greater than 10% reproduction (called a female index) on PI 88788 are commonly found now in most surveyed areas. Remember, 10% or less reproduction is the standard definition of resistance.

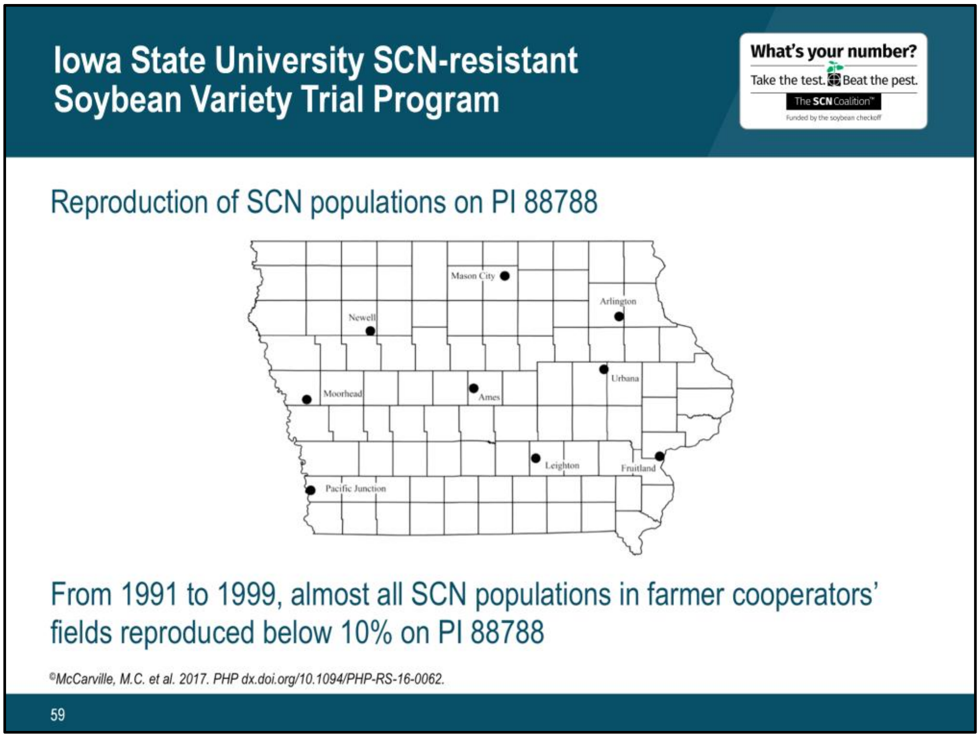
<u>PI 88788 previously provided effective resistance, but now the nematode is overcoming it, because we're seeing reproduction levels of 50% to 60% or more on PI 88788.</u>

A couple of the surveys have compared results to surveys done 10 or more years ago in the same area – and the recent results show greatly increased SCN reproduction on PI 88788.

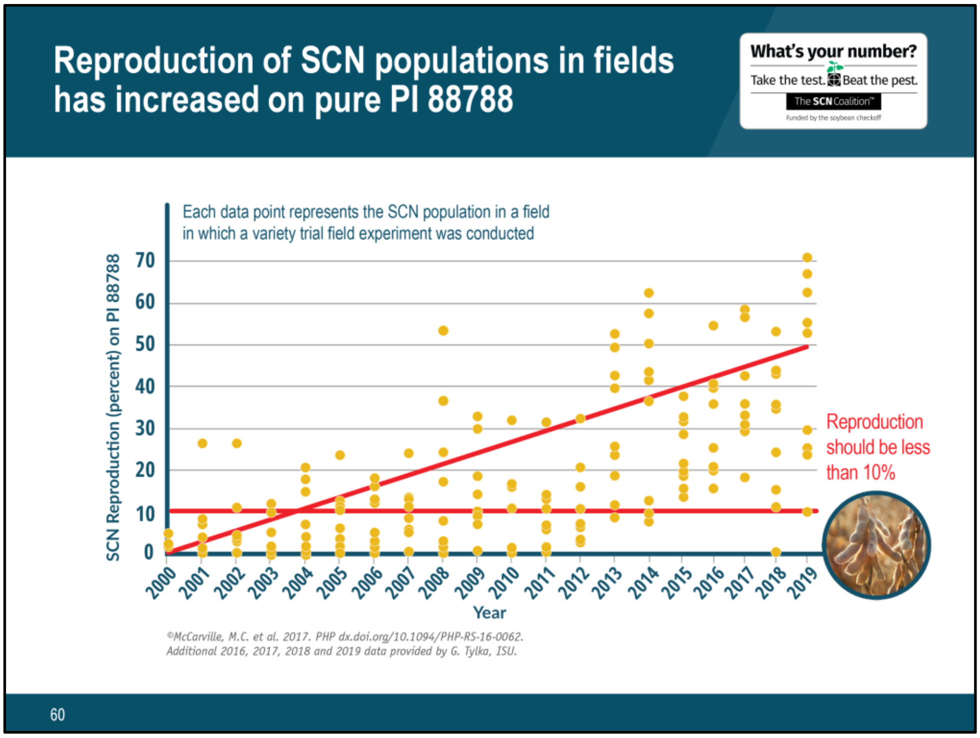
The most concerning thing is there's no way to go back. We can't un-do the buildup of farmers' SCN populations to feed and reproduce on PI 88788 resistance.



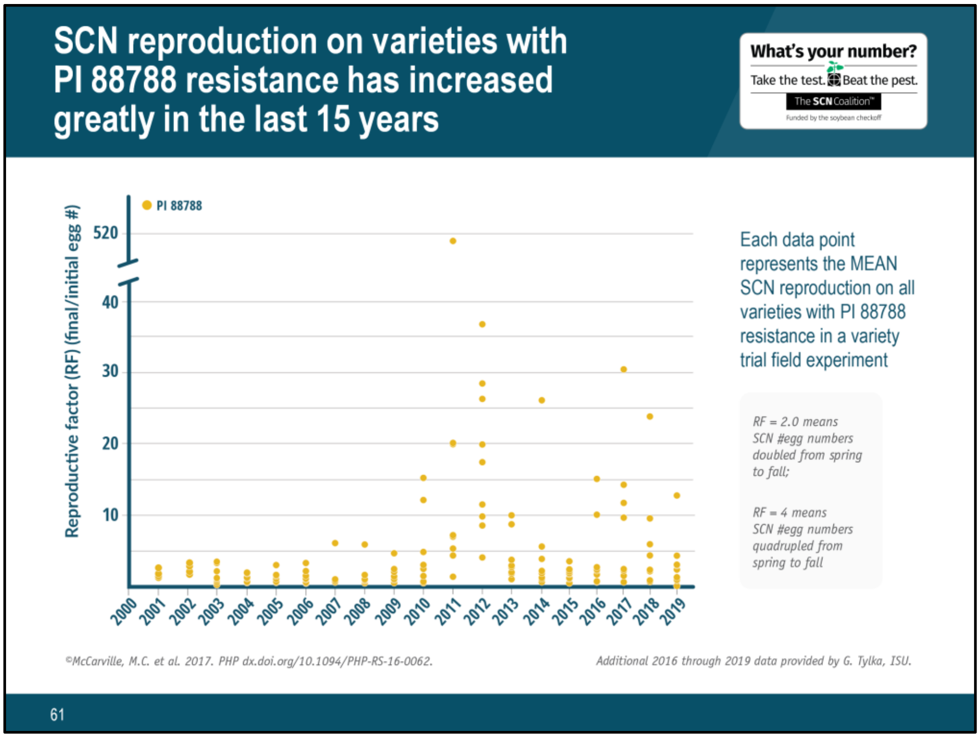
There has not been an HG type survey of Iowa conducted. But researchers in Iowa have evaluated resistant soybean varieties for decades in replicated “variety trial” experiments every year in nine locations in Iowa in farmers’ fields.
One of the first things done at the site of each experiment is to conduct an HG type test on the SCN population in each farmer’s field to assess how well the SCN population can reproduce on PI 88788 and the other sources of resistance.
So looking back at these variety trial reports, there are 25 years of information on the ability of SCN to reproduce on PI 88788 and the other sources of resistance in Iowa farmers’ fields.
Basically, this testing of the SCN populations in the fields used for the Iowa variety trials is somewhat like a non-random survey of SCN reproduction on PI 88788.



Recently, Iowa State researchers looked back at 25 years of data. And in the decade of the 1990s, almost all SCN populations in farmer-cooperators' fields were well controlled by PI 88788. Reproduction was below 10%.



Here's a graph of what happened starting in the year 2000. This is reproduction of the farmers' SCN populations on pure PI 88788.
Each data point represents a variety trial experiment in a farmer's field.
Throughout the 1990s and in 2000, reproduction was below 10%.
The red line represents the 10% reproduction level below which percent reproduction should be if resistance is effective.
As the years have progressed, it is obvious that SCN reproduction increases on PI 88788.
This illustrates in farmers' fields in Iowa, where researchers have conducted variety trials, the gradual buildup of nematodes on PI 88788.
It should be noted that individual, private farmers manages the fields in which these variety trial experiments were conducted. Researchers just rent a few acres of their land to do variety trials. The variety trials are never conduced in the same area twice – it's always in a new area (although perhaps in the same field) and always following corn. So these results are believes to be representative of what has happened and is happening in Iowa.

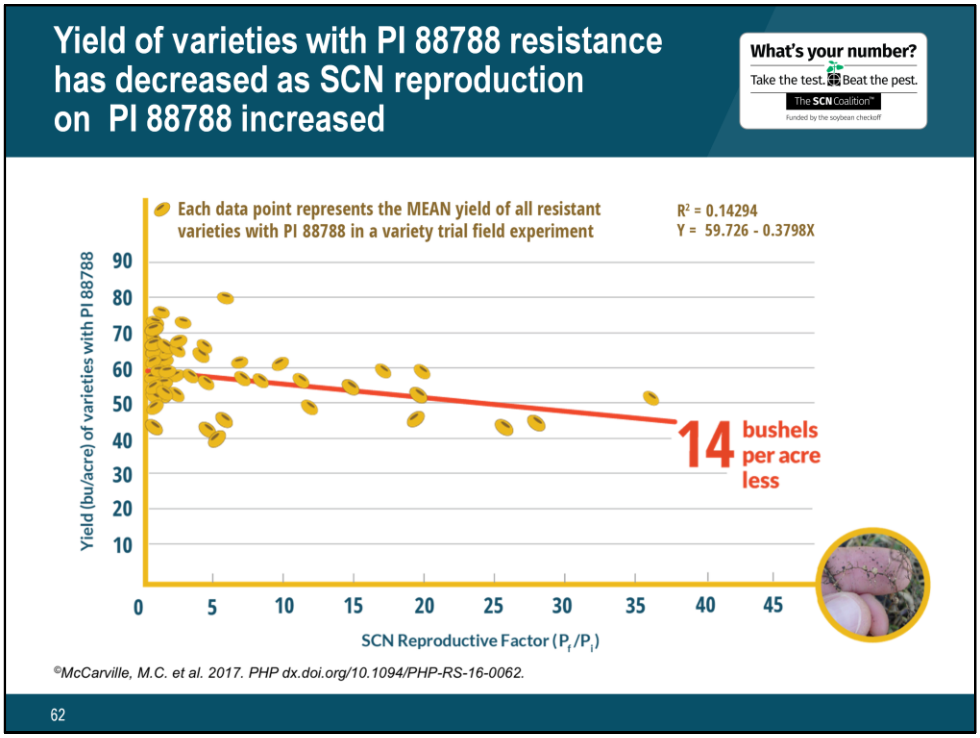


SCN egg population density data and yield data were collected in the variety trial experiments conducted in these fields. In this graph, years are at the bottom as was the case for the graph in the previous slide.

The Y axis here is the "reproductive factor," or RF, which is the end-of-season number of eggs divided by the beginning-of-season number of eggs in each replicated research plot.

An RF value of 2 means that there were twice as many eggs present at the end of the season as were present at planting and that the egg counts doubled during the season. An RF of 4 means the egg counts quadrupled.

We see RF values here of 10, 15, 20, 25 – and one crazy RF showing a 500-fold increase. This is reproduction (increase in egg numbers) on varieties with PI 88788 resistance in the variety trials.

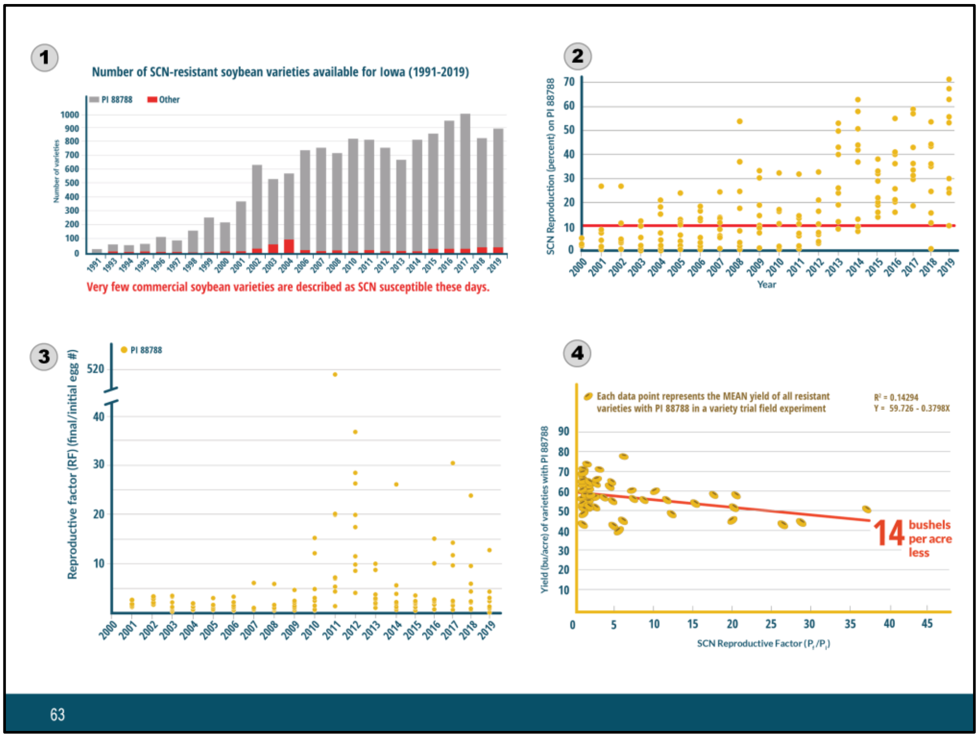


Yield data also were collected on the varieties in the variety trial experiments and are plotted in this graph versus the reproductive factor (RF) shown in the previous slide.

In this graph, RF is on the horizontal or X axis. Yield of those PI 88788 varieties is on the vertical or Y axis. There is a decrease in yields as SCN reproduction increased, which makes sense. As nematodes reproduce, the nematode is causing harm, and decreasing yields.

It doesn't look like a dramatic decreasing slope for this yield loss, but there is 14 bushels per acre difference in yield of resistant soybeans with PI 88788 between the end of line near zero and end of line where RFs are 30 or 40.

Clearly, resistant soybean varieties with PI 88788 are losing yield.



Here’s a summary slide of the situation in Iowa, and it’s probably representative of many Midwestern states:

1. Almost all varieties possess PI 88788 resistance.
2. SCN populations in farmers’ fields have built up the ability to reproduce on PI 88788 resistance.
3. Egg counts have increased under resistant varieties with PI 88788 grown in these fields.
4. Yields of resistant varieties with PI 88788 are dropping because of the increased reproduction.

It’s a cliché but it’s true: This is a train wreck in slow motion.

It is very likely that the usefulness of PI 88788 is going to continue to decline.
The days of the kind of growth improvement with PI 88788 SCN-resistant varieties, as shown in this picture, are numbered.
In fact, PI 88788 may provide very **little protection** against SCN in the future because SCN populations will have overcome the resistance.
It would take **considerable time**, effort, and cost to develop varieties with sources of resistance other than PI 88788. And farmers likely would not value such a trait enough to pay a premium for these varieties.
Because for decades, there was **no additional cost** for seed of SCN-resistant varieties compared to non-resistant or susceptible varieties.
Consequently, it is not likely that a lot of new varieties will be released with anything other than PI 88788 resistance.
We're kind of "in a pickle."

The third and final main management strategy is the newest: nematode-protectant seed treatments.

Nematode-protectant seed treatments

What's your number?
Take the test. Beat the pest.
The SCN Coalition™
Funded by the soybean checkoff

Brand name	Crop(s)	Targeted soybean nematodes	Active ingredient	Mode of action
Avicta Complete Syngenta	cotton, corn, soybean	all plant-parasitic nematodes	abamectin	inhibits nematode nerve transmission

Products labeled current as of January 2020

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N-Hibit Seed Treatment	all plants	all plant-parasitic nematodes	harpin protein	induces plant defenses

67 Products labeled current as of January 2020

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N-Hibit Seed Treatment Direct Enterprises	all plants	all plant-parasitic nematodes	harpin protein	induces plant defenses
Votivo BASF	cotton, corn, soybean	all plant-parasitic nematodes	*Bacillus firmus*	blocks infection, degrades eggs

68 Products labeled current as of January 2020

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N-Hibit® Seed Treatment Direct Enterprises	all plants	all plant-parasitic nematodes	harpin protein	induces plant defenses
Votivo® BASF	cotton, corn, soybean	all plant-parasitic nematodes	*Bacillus firmus*	blocks infection, degrades eggs
Clariva™ pn Syngenta	soybean	SCN	*Pasteuria nishizawae*	nematode parasite

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N-Hibit® Seed Treatment Direct Enterprises	all plants	all plant-parasitic nematodes	harpin protein	induces plant defenses
Votivo® BASF	cotton, corn, soybean	all plant-parasitic nematodes	*Bacillus firmus*	blocks infection, degrades eggs
Clariva™ pn Syngenta	soybean	SCN	*Pasteuria nishizawae*	nematode parasite
ILEVO® Seed Treatment BASF	soybean	SCN, root-knot, reniform, lesion	fluopyram	inhibits nematode cellular respiration (SDHI)

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N-Hibit® Seed Treatment Direct Enterprises	all plants	all plant-parasitic nematodes	harpin protein	induces plant defenses
Votivo® BASF	cotton, corn, soybean	all plant-parasitic nematodes	*Bacillus firmus*	blocks infection, degrades eggs
Clariva™ pn Syngenta	soybean	SCN	*Pasteuria nishizawae*	nematode parasite
ILEVO® Seed Treatment BASF	soybean	SCN, root-knot, reniform, lesion	fluopyram	inhibits nematode cellular respiration (SDHI)
AVEO™ EZ Valent	corn, soybean	SCN, root-knot, reniform, lesion, others	*Bacillus amyloliquefaciens*	paralyzes nematodes

Products labeled current as of January 2020

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N-Hibit® Seed Treatment Direct Enterprises	all plants	all plant-parasitic nematodes	harpin protein	induces plant defenses
Votivo® BASF	cotton, corn, soybean	all plant-parasitic nematodes	*Bacillus firmus*	blocks infection, degrades eggs
Clariva™ pn Syngenta	soybean	SCN	*Pasteuria nishizawae*	nematode parasite
ILEVO® Seed Treatment BASF	soybean	SCN, root-knot, reniform, lesion	fluopyram	inhibits nematode cellular respiration (SDHI)
AVEO™ EZ Valent	corn, soybean	SCN, root-knot, reniform, lesion, others	*Bacillus amyloliquefaciens*	paralyzes nematodes
escalate nemasect Beck's / BIO ST Albaugh	corn, soybean	all plant-parasitic nematodes	heat-killed *Burkholderia rinojensis* and fermentation media	not stated

72 Products labeled current as of January 2020

Nematode-protectant seed treatments

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Votivo BASF	cotton, corn, soybean	all plant-parasitic nematodes	*Bacillus firmus*	blocks infection, degrades eggs
Clariva pn Syngenta	soybean	SCN	*Pasteuria nishizawae*	nematode parasite
ILEVO Seed Treatment BASF	soybean	SCN, root-knot, reniform, lesion	fluopyram	inhibits nematode cellular respiration (SDHI)
AVEO EZ Valent	corn, soybean	SCN, root-knot, reniform, lesion, others	*Bacillus amyloliquefaciens*	paralyzes nematodes
escalate nemasect Beck's | BIO ST Albaugh	corn, soybean	all plant-parasitic nematodes	heat-killed *Burkholderia rinojensis* and fermentation media	not stated
Trunemco Nufarm	cotton, corn, soybean	SCN, root-knot, reniform	*Bacillus amyloliquefaciens* and cis-Jasmone	induces plant defenses and systemic resistance

Products labeled current as of January 2020

Nematode-protectant seed treatments

What's your number?
Take the test. Beat the pest.
The SCN Coalition
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Brand name	Crop(s)	Targeted soybean nematodes	Active ingredient	Mode of action
Avicta Complete Syngenta	cotton, corn, soybean	all plant-parasitic nematodes	abamectin	inhibits nematode nerve transmission
N-Hibit Seed Treatment Direct Enterprises	all plants	all plant-parasitic nematodes	harpin protein	induces plant defenses
Votivo BASF	cotton, corn, soybean	all plant-parasitic nematodes	*Bacillus firmus*	blocks infection, degrades eggs
Clariva pn Syngenta	soybean	SCN	*Pasteuria nishizawae*	nematode parasite
ILEVO Seed Treatment BASF	soybean	SCN, root-knot, reniform, lesion	fluopyram	inhibits nematode cellular respiration (SDHI)
AVEO EZ Valent	corn, soybean	SCN, root-knot, reniform, lesion, others	*Bacillus amyloliquefaciens*	paralyzes nematodes
escalate nemasect Beck's | BIOST Albaugh	corn, soybean	all plant-parasitic nematodes	heat-killed *Burkholderia rinojensis* and fermentation media	not stated
Trunemco Nufarm	cotton, corn, soybean	SCN, root-knot, reniform	*Bacillus amyloliquefaciens* and cis-Jasmone	induces plant defenses and systemic resistance
Saltro Syngenta	soybean, other crops (not cotton, corn)	SCN, root-knot, reniform, lesion, lance	pydiflumetofen	inhibits nematode cellular respiration (SDHI)

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Nematode-protectant seed treatments

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- Most are bundled with seed-treatment insecticides
- N-Hibit is available direct to the farmer
- Large seed companies do not offer a choice of more than one nematode-protectant product on their seed
- Can increase yields, but results may vary among fields and growing seasons
- SCN population densities will resurge when protection wears off

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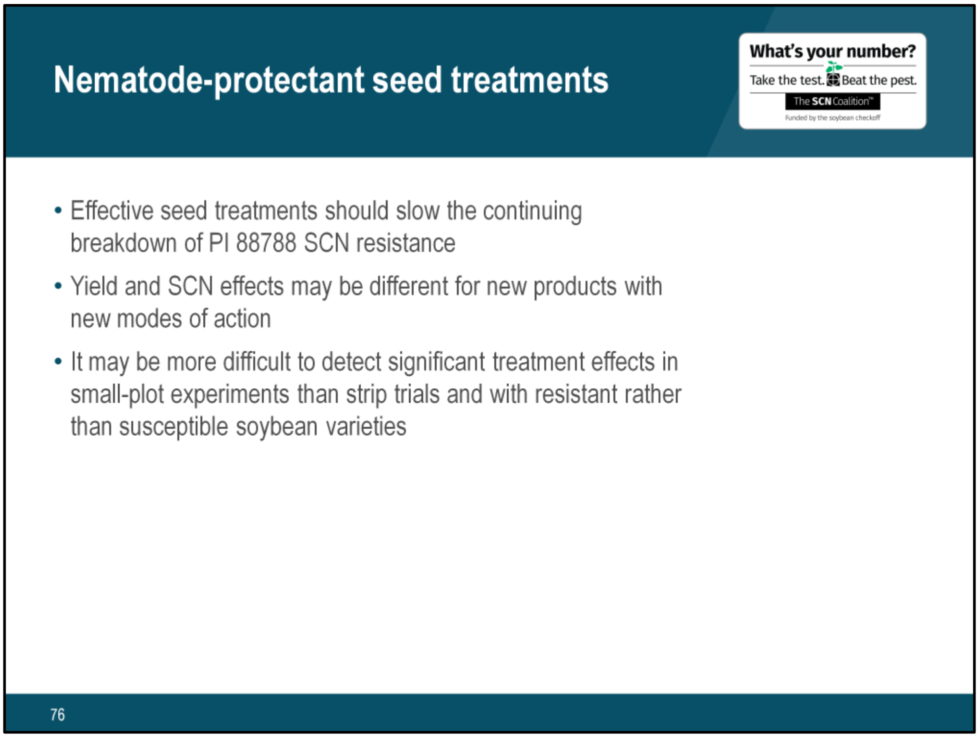
Here are some final thoughts on nematode-protectant seed treatments.
Fore the most part, a farmer can't just buy the nematode-protectant seed treatment because almost all are bundled on top of base seed-treatment insecticides and fungicides.
The one exception is the N-Hibit product, which farmers can buy directly and apply themselves.
Also, most of the large seed companies have aligned themselves with one lineup of nematode-protectant seed treatments.
If you want a particular seed treatment, that'll steer you -- at least among the large companies -- toward one seed company's lineup of soybean varieties.
The nematode-protectant seed treatments can increase yields, but the results may vary among fields and among growing seasons. And SCN population densities will build back up as the protection wears off.

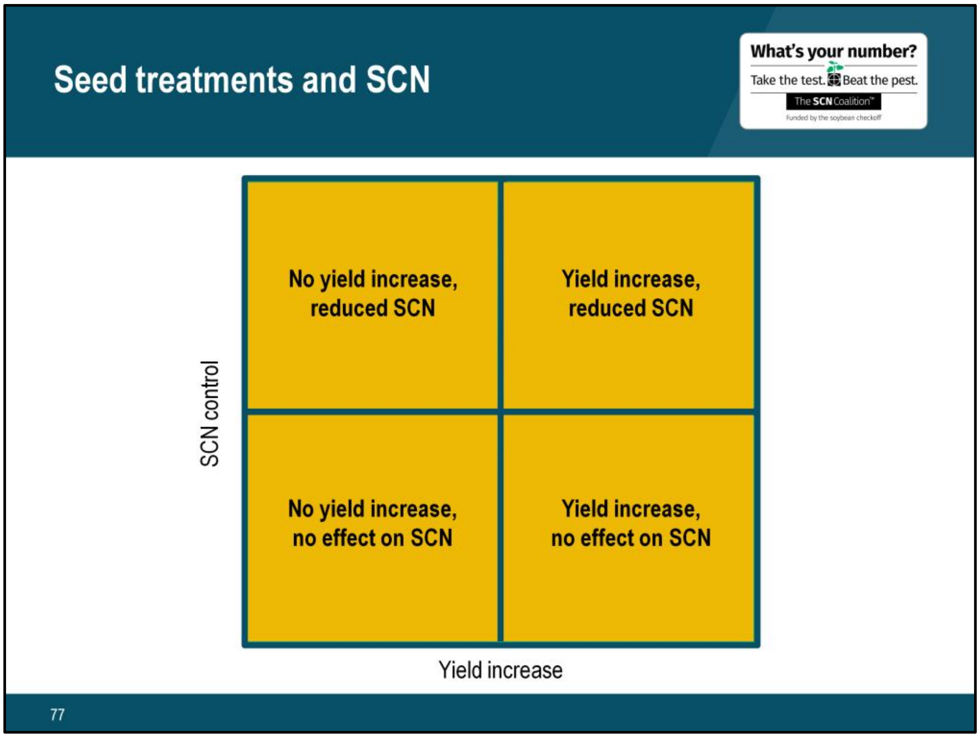


But there may be an added benefit to the seed treatments: We hope the seed treatments slow down the gradual breakdown of PI 88788 resistance.

Another optimistic thought: We don't know what's out there that will come to market next. Every nematode-protectant seed treatment product seems to have a new mode of action, a new mechanism, so it's hard to even guess what will be next.

One last final point: University researchers use small plot equipment to do field experiments with seed treatments such as these. It might be easier to get significant differences in strip trials rather than small plot experiments (especially yields).

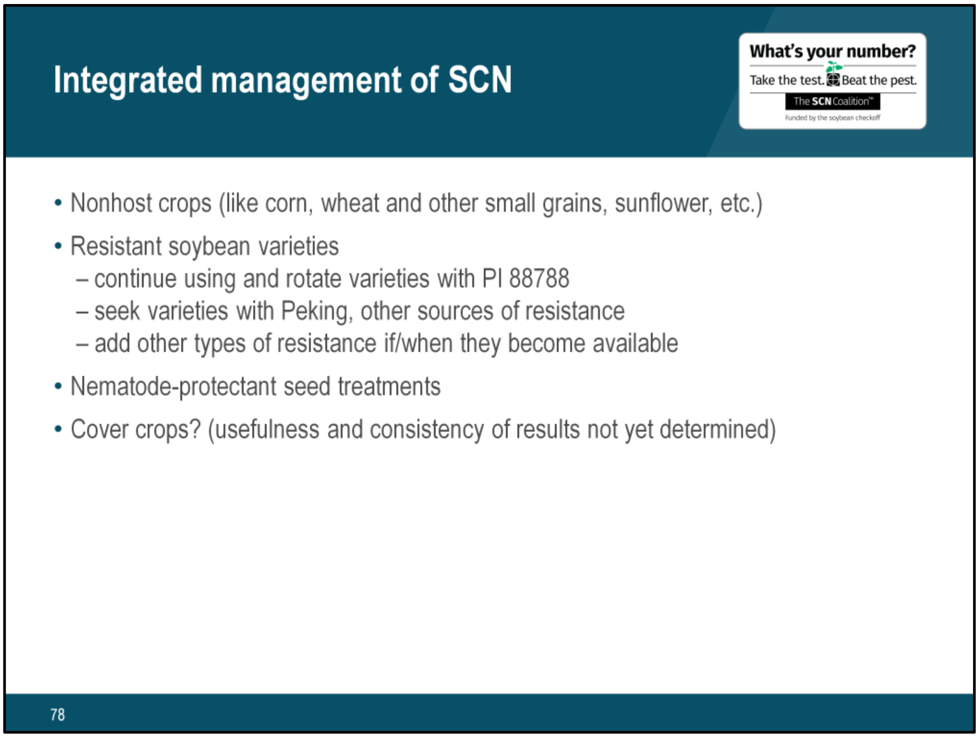
Also, evaluations of nematode-protectant seed treatment products are done on resistant soybeans. Significant treatment differences may be more apparent with susceptible varieties. But the seed treatments are to be used on resistant seeds, so that's a more realistic way to evaluate them.



This is how to **conceptualize** the possibilities of using seed treatments for nematode protection.
SCN control is on the vertical or Y axis, and yield increase is on the horizontal or X axis.
There are four possibilities:

- **No yield increase, no effect on SCN**
- **Yield increase, no effect on SCN**
- **No yield increase, reduced SCN**
- **Yield increase, reduced SCN**

And the worst place to end up at the end of the season, is no yield increase and no nematode control.
The top right is where we want to be consistently.



This is the future of managing SCN:

- We want people to grow nonhost crops because it lowers nematode numbers.
- We have to keep growing resistant soybeans – even those with PI 88788 – because we don't have a choice.
- Farmers need to seek out varieties with Peking and other sources of resistance. If something new comes on the market, we'll need to adapt and adopt those as well.
- We need to consider using the nematode-protectant seed treatments.

There are a lot of questions about cover crops and if they could play a role in managing SCN. To this point, there is hope that some cover crops, under some conditions, can reduce SCN numbers more than if there was no cover crop grown, but the consistency of such benefits has yet to be determined.

THANK YOU for listening! Any questions?