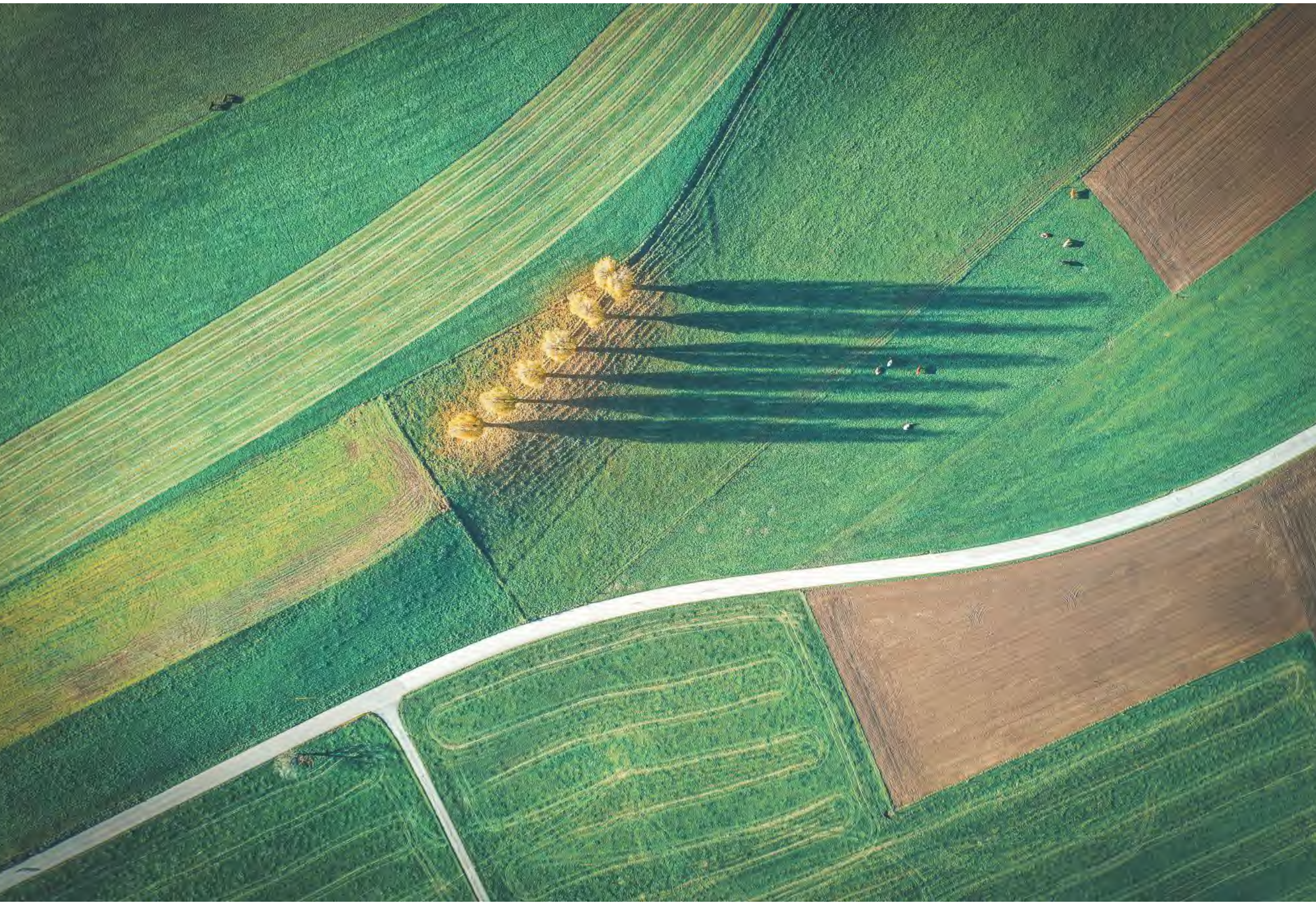

State of the Industry report

Pathogen damage in North America

Executive Summary

Soybean farmers in the US lose approximately $5.5B annually in yields due to pests and disease damage in spite of spending $1.5B[1] each year on fungicides, insecticides, and other treatments.

The leading categories driving this loss are fungal diseases ($3.2B/yr), nematodes ($1.5B/yr), and insects ($2.4B/yr).

This report will show that proper detection and timely target application could prevent losses up to $225M/yr for fungi, $330M/yr for nematodes, and $886M/yr for insects.

Key Takeaways

Early and specific detection is the critical factor in maximizing the effectiveness of yield-saving mitigation measures with the potential to reclaim $1.4B of value for soybean farmers annually. However, existing tools are limited to detecting general stresses after significant damage has already occurred.

A seed-based, plant-centric platform would provide specific detection of stresses weeks before existing methods and enable farmers to optimally apply mitigation measures that prevent yield loss while reducing costs from applying chemicals when less effective.

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[1] At an average of $17 per acre

Our Findings

Soybean farmers in the US lose approximately $5.5B annually in potential yield destroyed by pests and diseases *(Chart 1)*. We studied dozens of reports by the USDA, APS Journals, farmer journals, University publications, and McKinsey. We then consulted with experienced farmers and agronomists to compile the following report which outlines the major pathogens, best practices for pathogen control, and the potential value that will be unlocked with early specific detection.

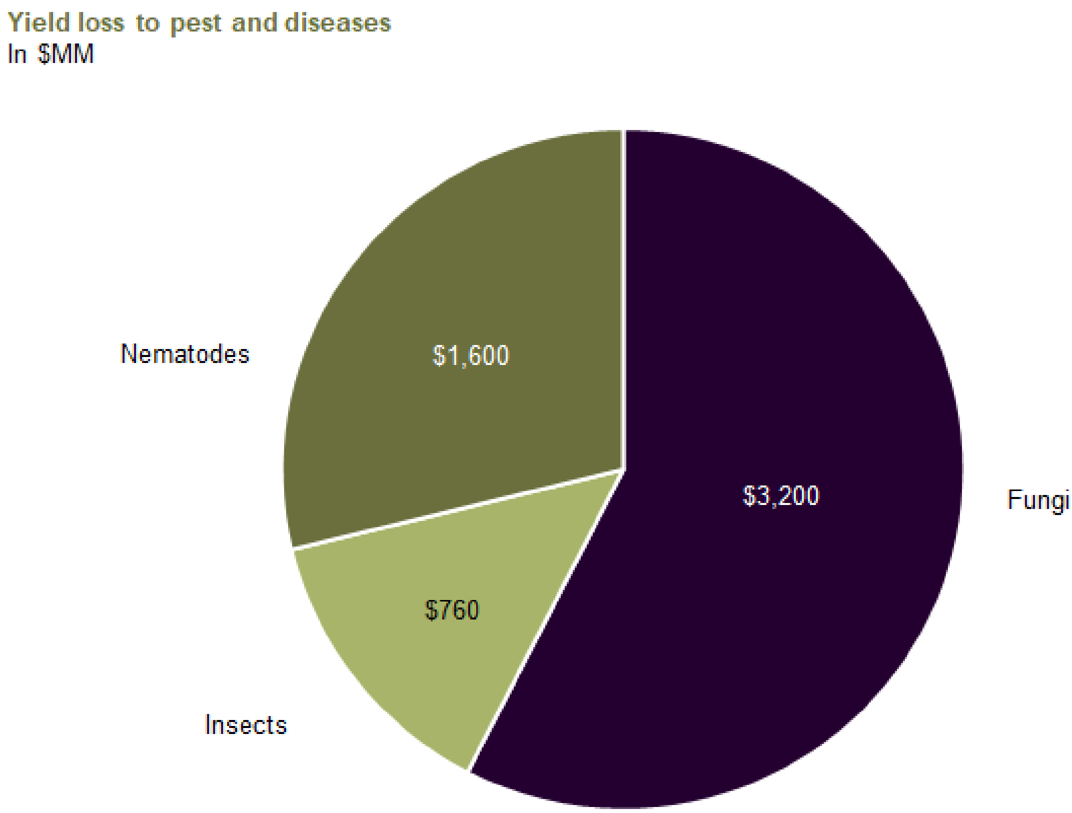

Chart 1: Yield loss to pests and diseases

Section I – Fungal Diseases

Fungal diseases affect soybean farmers in three ways:
1. Yield reduction resulting from fungal crop damage
2. Higher costs resulting from preventative or reactive fungicide applications
3. Lower yield potential due to reduced planting density per acre

Fungal diseases in aggregate cost American farmers $3.2 billion annually in yield loss while spending $158 million annually on fungicide applications[2]. These dynamics represent an opportunity to increase yield through targeted and timely crop protection applications. For example, in Brazil, Asian Soybean Rust (ASR) historically created crop destruction resulting in $2B annual yield loss, since the introduction of a dedicated pesticide 2 decades ago, the damage to ASR has been eliminated at a cost averaging $25 an acre.

Many fungal diseases emerge in vegetative states and are not detected through conventional scouting, but manifest in later stages of the crop life cycle, creating unexpected yield loss, which could be prevented by understanding the relationship between the etiological agent, the host, and the environment at earlier stages. Some fungal diseases can be prevented through seed treatments, others can be eliminated through fungicide applications, and some diseases have no dedicated solution available today *(Chart 2)*. However, as more data is gathered and new innovations in crop protection are launched we believe there could be new solutions for these diseases that today are untreatable.

2 https://apsjournals.apsnet.org/doi/pdf/10.1094/PHP-RS-16-0066#:~:text=The%20average%20annual%20yield%20losses,Jansen%2C%20Castl.

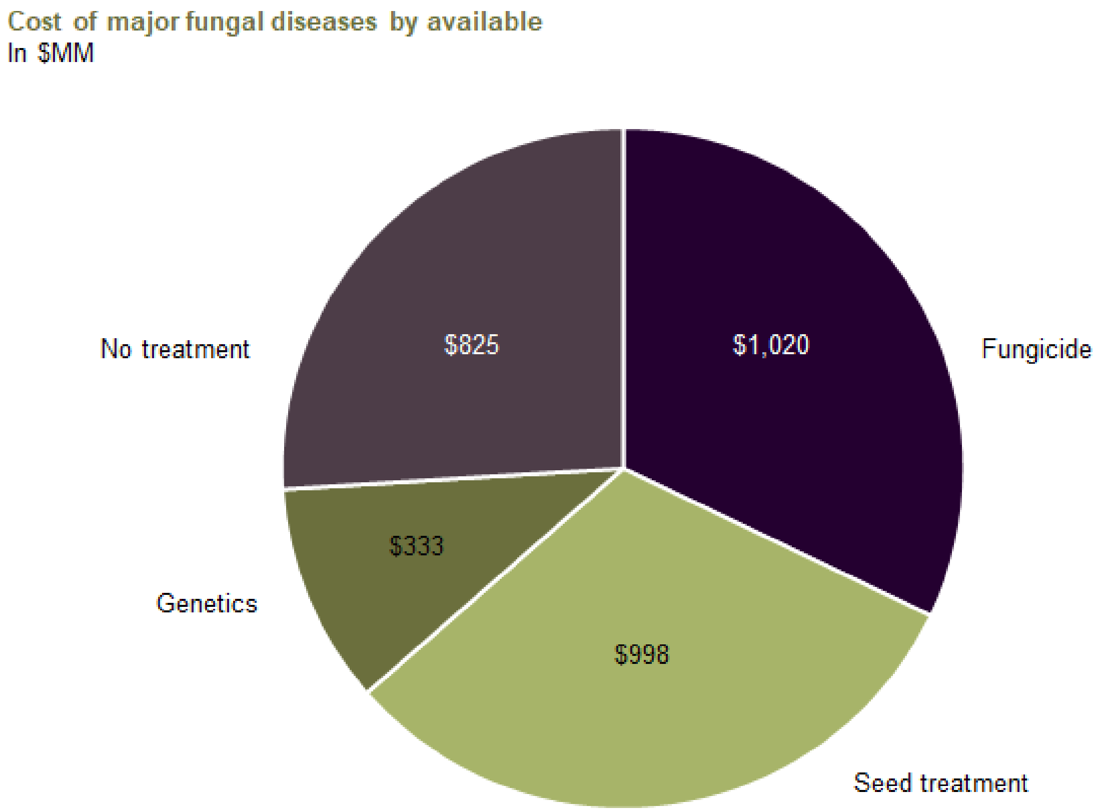

Chart 2: Segmentation of major fungal disease impact by available solutions

Break down by fungi type (Chart 3)

For White Mold management, several products such as Aproach, Endura, and Proline have been rated as having 'good' efficacy, depending on the ability of the fungicide to penetrate into the canopy and the timing of the application. Applications at the R1 stage are more effective than applications at later stages.

Septoria and Cercospora on the other hand, are better addressed via fungicides applications between stages R2 and R5. Spraying at the R3 stage is optimal, and it can reduce white mold yield loss by 21%, representing an additional 3.6 bushels per acre.

Available solution	Disease	Disease common name	2014 loss (1000 bushels)	Loss ($1000)
Fungicide	Sclerotinia sclerotium	Sclerotinia stem rot (white mode)	40,855	$367,695
	Septoria Glycines	Septoria brown spot	27,398	$246,582
	Cercospora sojina	Frogeye leaf spot	18,147	$163,323
	Diaporthe sojae	Pod and steam blight	13,383	$120,447
	Colletotrichum	Anthracnose	3,325	$29,925
	Cercospora kikuchii	Cercospora leaf blight or	10,222	$91,998
Seed treatment	Fusarium	Sudden death syndrome	63,484	$571,356
	Phytophtora sojae	Phytophthora root and stem rot	34,565	$311,085
	Diaporthe caulivora	Stem canker	12,842	$115,578
Genetics	Macrophomina phaseolina	Charcoal rot	26,793	$241,137
	Diaporther longicola	Phomopsis seed decay	10,242	$92,178
No treatment	Rizocthonia, phythium, fusarium, Phomopsis	Seedling diseases	64,457	$580,113
	Phialophora gregata	Brown stem rot	13,715	$123,435
	Fungii	Other diseases	5,740	$51,660
	Fusarium	Fusarium wilt and root rot	5,662	$50,958
	Penospora Manshurica	Downy mildew	1,348	$12,132
	Sclerotium rolsfii	Southern blight	696	$6,264
	Phakopsora Pachyrhizi	Soybean rust	45	$405
Total			**352,919**	**$3,176,271**

Chart 3: Break down by fungi type

According to our conservative models, reliable detection of fungal pressure resulting in a timely target application of broad range fungicides could generate $225 million per year for American soybean growers by preventing yield loss to diseases (Chart 4)[3].

[3] https://loss.cropprotectionnetwork.org/crops/soybean-diseases?year_start=2010&year_end=&diseaseCategory=&diseases%5B%5D=50&country=1&region=&cropID=2

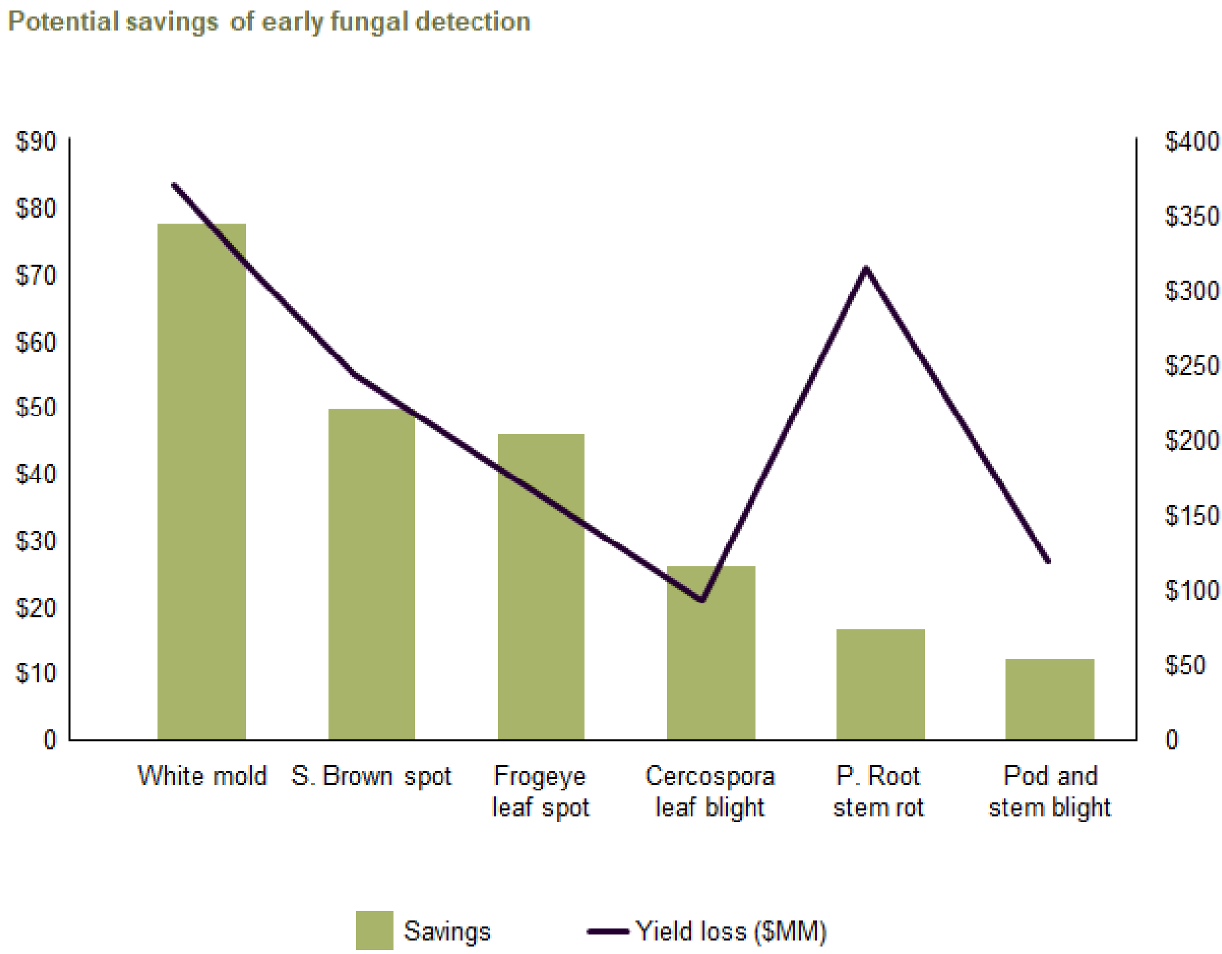

Chart 4: Potential savings by treating fungal diseases

Only 18% of soybean and corn farmers bear fungicide application costs[4]. Preliminary research shows that applying fungicide *at the right time* can increase yield by 15% for soybeans. When investigating this with pathologists, the reasoning was that there is always some amount of fungal pressure, and by alleviating it at the correct time, the plant can focus its resources into growing, creating higher yields and a positive ROI for the farmer. In addition to fungicides, farmers can plant coated seeds if the intensity of fungal pressure is above a certain threshold.

Some analyses indicate that 36% of soybean varieties end up incurring yield losses even after an application of fungicides. This is a result of farmers confusing the type of disease affecting their crops or of applying the wrong fungicide for a specific variety. In addition, applying fungicides has negative effects on soil fertility, further reducing yield in subsequent years.

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[4] https://www.nass.usda.gov/Statistics_by_State/Iowa/Publications/Other_Surveys/2019/IA-Ag-Chem-Corn-Soybeans-2019.pdf

Another 36% of varieties result in negative Return on Investment (ROI)[5] (see chart 5) which means that 1 out of 3 applications of fungicides currently do not offer financial benefits to farmers. We believe these are the reasons most US soybean farmers do not apply fungicides and instead anticipate some amount of crop loss to fungal diseases each season.

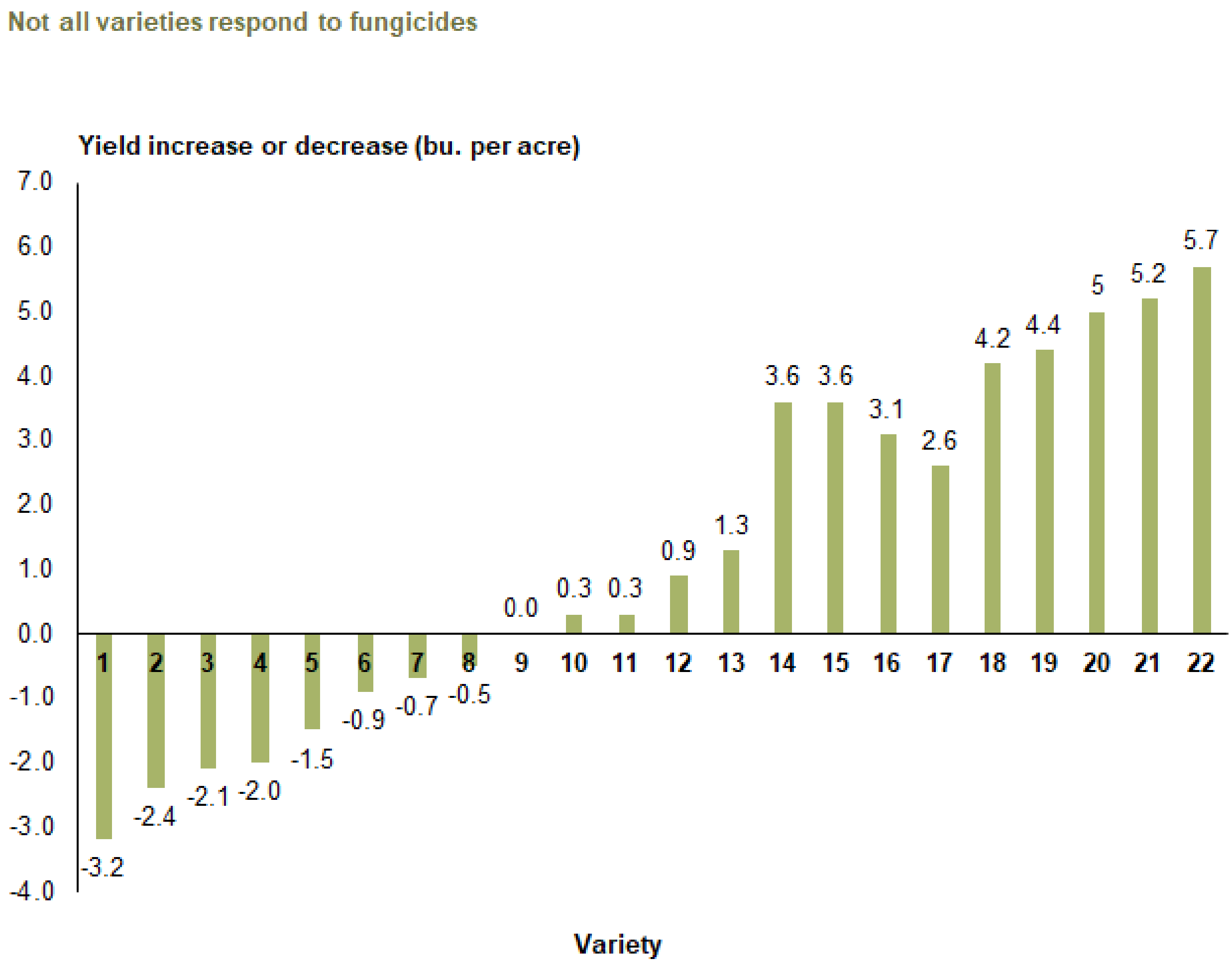

Chart 5: Some varieties have negative ROI for fungicide applications

[5] https://www.agweb.com/news/machinery/100-ideas/evaluate-fungicide-factor

The average gains from applying fungicides at the R2 and R3 stages were 2.5 bushels per acre, 60% higher than applications at the R4 stage[6]. These data outline the importance of early detection of fungal pressure which enables applications of fungicides at the optimal stages (R2 and R3) improving ROI of fungicides by 60%. Lastly, farmers spend ample time identifying where to spray, selecting the application products, and the optimal time. A crop-centric alert system will remove the need for analysis and manual scouting and will ensure the optimal course of action.

Even when applying conservative estimates, we identified a potential value for US soybean farmers of $922 million annually by early detection of fungal stresses. This is an aggregate of 30% reduction in the current yield loss to fungal diseases and 70% reduction in negative ROI fungicides applications.

[6] https://www.agweb.com/news/machinery/100-ideas/evaluate-fungicide-factor

Section II - Nematodes

Plant parasitic nematodes are the cause of 150 million bushels lost annually in the US[7], costing American farmers around $1.5 billion annually. Soybean Cyst Nematode (SCN) is the most prevalent pest in this category. SCNs exist across the country, but most damage happens in lighter soils. Root-knot nematodes tend to occur in sandier soils and Reniform in sandy to silty loams. Unfortunately, weather conditions which favor optimal soybean yields are also the optimal conditions for SCN reproduction (chart 6).

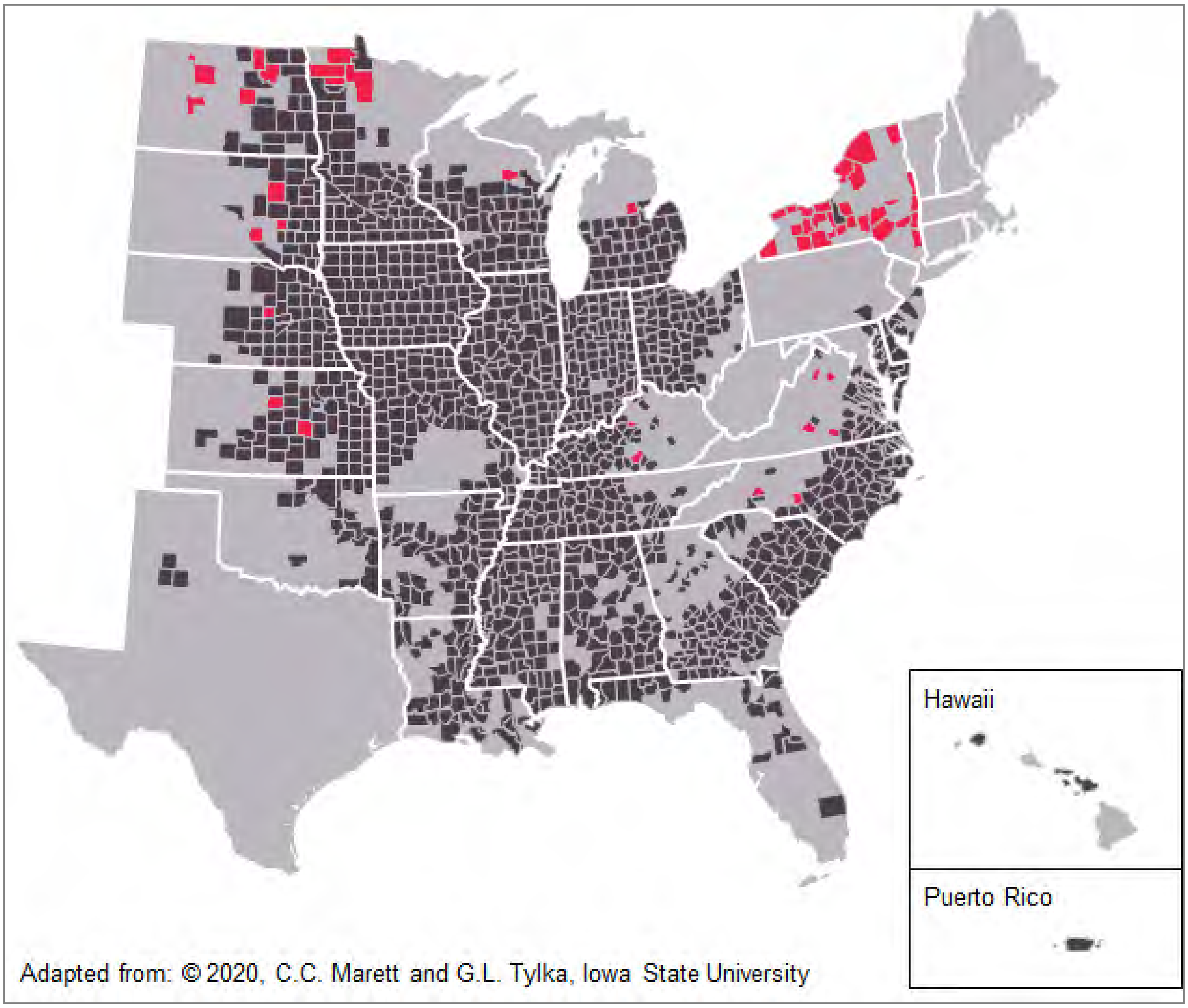

Chart 6: Presence of CSN in US counties. Distribution of SCN across the US (blue signals the states where the disease appeared for the first time recently)

[7] https://apsjournals.apsnet.org/doi/10.1094/PHP-RS-16-0066

Soybean Cyst Nematode (SCN) is the major nematode threat, causing $1.1 billion of annual yield loss to US soybean farmers. Followed by Southern root-knot and Reniform, both of which are more prevalent in the Southern producing regions.

Standard detection techniques in use today make it challenging to diagnose SCN, as the phenotyping signs look similar to fungal diseases. Stunting, yellowing, early death, and low yields are common symptoms of nematode injury. Oftentimes, however, symptoms occur below the surface in the root system, therefore the progression of SCN can go unnoticed until damage is severe. This is risky if left unmanaged, as population densities and potential yield loss increase rapidly. SCN pressure can increase presence from 30% to 70% in a single year, so the impact of undetected SCN can be devastating. Even without aboveground symptoms, SCN can still incur 10-15% yield loss.[8] In some states such as Nebraska, some amount of SCN pressure is present in over 90% of the farms, which makes it hard to know when taking an action will have a positive ROI.

It is recommended that farmers in SCN regions take soil samples each 10 acres, but given the costs (time of taking around 20 samples + $20 lab testing + $150 if the disease is found and more specific details on the raze are needed), many farmers take one sample per field. In some American states, there are subsidies and governmental programs to do soil samplings.

While soil samples are important indicators of SCN growth, soil data may be unreliable in times of high nematode productivity. A soil sample may demonstrate an egg count below a given threshold, but rapid reproduction on a cultivar may result in a 5 to 10-fold increase in egg population by the end of the growing season.[9] Pairing soil data with real-time plant based monitoring, therefore, keeps growers informed of volatile conditions when timing is critical.

Early diagnosis would allow farmers to opt for more resistant seed varieties, invest in seed treatments, or rotate crops the following season. It is recommended not to plant the same variety of SCN resistant seeds in closeby years[10]. There are also a few seed treatment nematicides such as: Avicta Complete Bean, Poncho Votivo, and ILeVO.

The ability to more accurately predict SCN growth even before planting is highly advantageous, as SCN-resistant soybeans often compromise yield potential. In years of low SCN infestation, non-resistant cultivars may often be the better choice.[11] While it may be difficult to predict unpredictable environmental and soil conditions that will determine the extent of SCN influence, having a firm grasp on moisture levels via plant based sensors allows for greater decision-making power. A reliable understanding in the state of the crops and land enables the proper timing of crop rotations between non-host, non-resistant soybean, and resistant soybean cultivars.

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[8] https://www.ndsu.edu/pubweb/~bernelso/soydiseases/cyst.shtml
[9] https://www.ndsu.edu/pubweb/~bernelso/soydiseases/cyst.shtml
[10] https://soybeanresearchinfo.com/soybean-disease/soybean-cyst-nematode-scn/
[11] https://www.ndsu.edu/pubweb/~bernelso/soydiseases/cyst.shtml

Depending on the nematode, rotating crops vary. For SCN, corn, cotton, grain sorghum, wheat, sugarcane, and rice are good rotational crops, while for Southern root-knot corn is an excellent host as is cotton for Reniform - which means other crops such as peanut and rice would be better at terminating the life cycle of such nematodes.

Solely by preventing the worst years where farmers get up to 30% yield loss would allow farmers to save $330 million per year.

Section III: Insects

It is estimated that Insect damage reduces yield by 2% in the United States[12], costing American farmers $1B in yield loss annually, with some farms seeing up to 35% yield loss in a bad year. Different from fungi and nematodes, American soybean farmers spend $1.8B in insecticide applications in order to reduce the insect infestations and damage, and this is growing each year (*Chart 7)*.

To reduce development of resistance to BT traits, soybeans have been restricted in the US from including BT traits. Corn and cotton are the primary rotation crops that have BT traits and have been an effective method to reduce overall insect pressure for soybeans. However, over the past years there has been an increased threat with many resistant insects evolving, risking the overall future efficacy of BT.

In order to slow down resistance to BT, the EPA implemented Integrated Pest Management (IPM) protocols which include the enforcement of refuge crops[13]. Currently the IRM requirement for corn is 5% refuge in a bag (RIB) and 20% structured refuge in the South where cotton and corn plantings overlap. The EPA is proposing to increase the RIB to 10% in this region to delay resistance to pests that are high risk (heterozygote pests for resistance that are not controlled by the level of expression of specific Bt proteins in corn).

Chart 7 shows the increased need farmers saw over the past decades for insecticides to protect against insects. This trend alongside the increased restrictions in IRM will likely continue exposing farmers to additional risks and costs in insect management.

To prevent insects there are proactive and responsive solutions: Proactive solutions include insecticide seed treatment, modified planting dates, elimination of alternate host plants, trap cropping. Responsive solutions include foliar insecticide sprays and inundative release of biocontrol agents. Late season pests are managed through scouting, while early season threats are usually managed through historic data.

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12 https://www.ag.ndsu.edu/research/documents-impact-statements/s1039-impact-statement-pdf#:~:text=Insect%20pests%20hinder%20soybean%20growth,year%20from%202004%20to%202010.

13 https://www.epa.gov/regulation-biotechnology-under-tsca-and-fifra/insect-resistance-management-bt-plant-incorporated

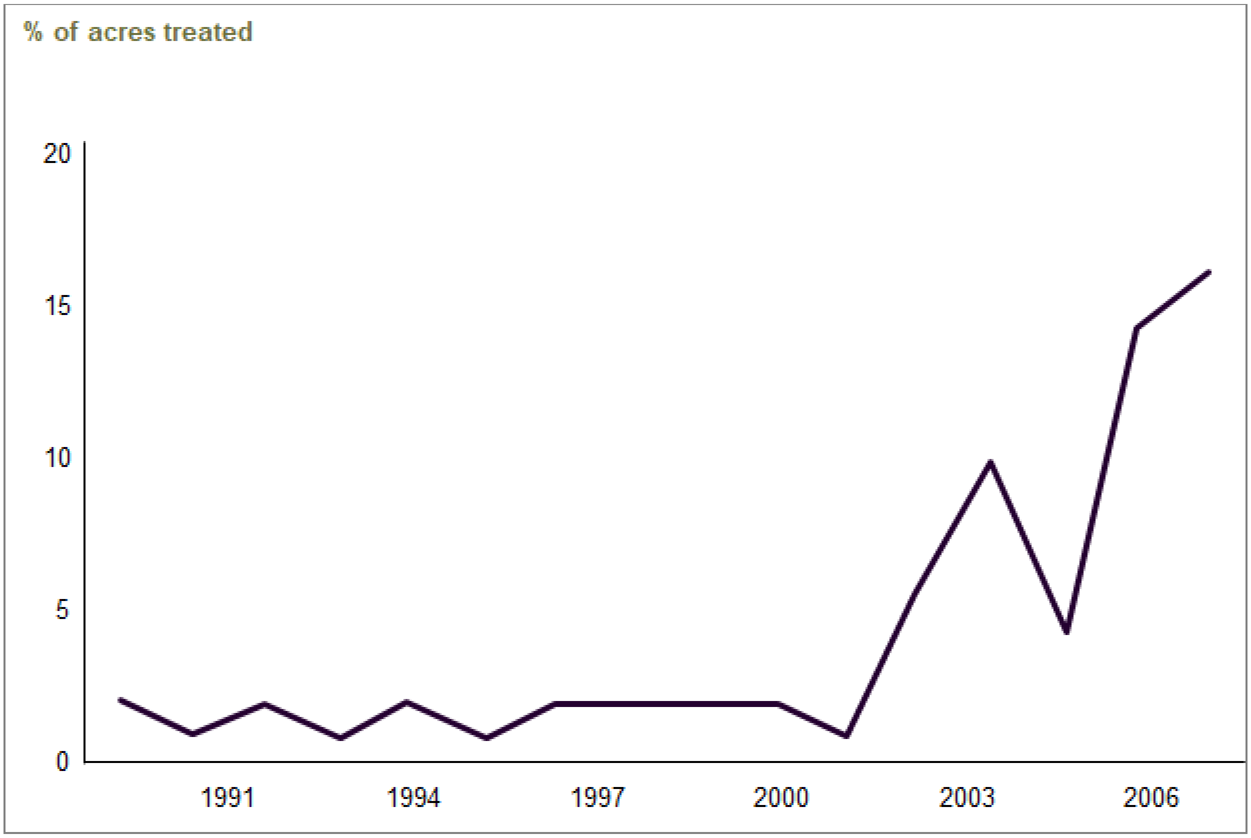

Chart 7: insecticides application in the US

Out of the 700 invertebrates that habit US soybean fields, only 20 are considered major economic pests[14]. Out of those, most could poise a great threat if a great population attacked certain types of soybean fields (e.g. in warmer or colder regions, planted earlier or later in the season, fields that were converted from grasslands) but haven't caused any economic damage in the previous 50 years.

Pest management as a whole is a balancing act that requires strategic division of efforts between identifying new sources of infestation while tracking existing ones. With the constant threat of pest encroachment, pressure to quickly identify and limit the spread of pests requires the frequent surveying of fields. Not only must their presence be detected, but the extent of defoliation must also be tracked to determine a treatment response. The constant sampling of plants is thus a highly labor intensive process, requiring strategies that locate which plants will best represent the conditions of the field at large.

The pod formation and reproductive stages are crucial periods of soybean development that determine yield. Stink bugs, aphids, and pod worms are highly active during these stages, and catching these pests before they can incur significant damage is critical. Large populations gone undetected will cause severe defoliation and yield loss. On the other hand, spraying too early

[14] https://apsjournals.apsnet.org/doi/pdf/10.1094/9780890544754.fm

can result in negative ROI for farmers, who should take action right when the Economic Threshold of insects is met and before there is any Economic Injury Level *(Chart 8)*.

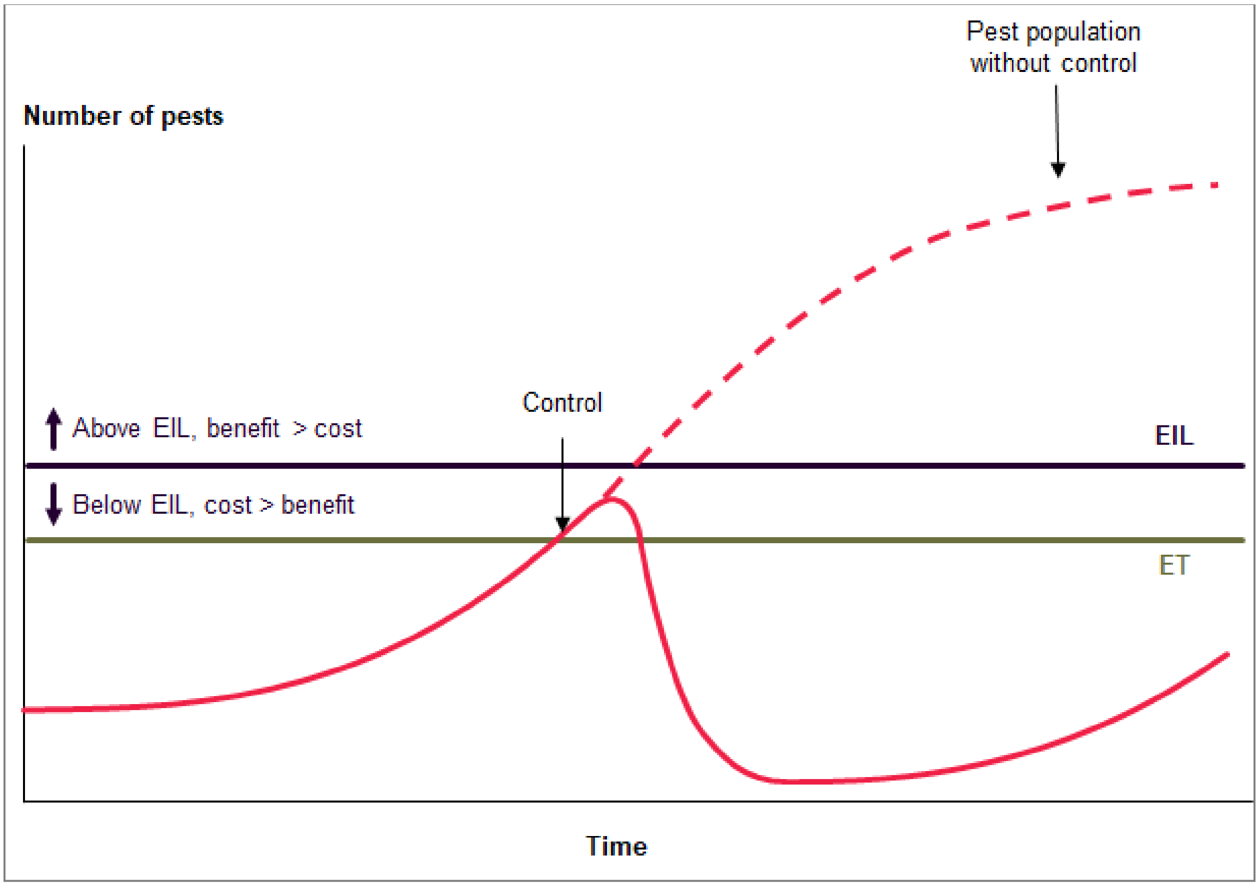

Chart 8 : When to spray against insects

Another approach to decide when to take action is based on leaf defoliation. A general approach is to act as soon as 30% of leaf-area is lost before bloom stages and 15% thereafter; however, there is a tendency to overestimate foliage loss (partly because insects often feed in the upper leaves, and partly because the eye tends to focus more on damaged areas)[15]. One way to calibrate is to remove trifoliate leaves from the top, middle, and lower part of the canopy without looking and then take the measurements of missing areas.

Insects vary across main producing regions. In the Midwest, soybean aphid reduces production value by 3% with some fields seeing a 40% loss in a bad year, causing an estimated annual loss of $2.4 billion. In the Mid-South, up to 70% of acreage is treated for stink bugs, corn

15 https://www.clemson.edu/extension/agronomy/pestmanagement17/insect%20control%20in%20soybean.pdf

earworm, and other lepidopteran defoliators each year, with the estimated value of yield loss plus management costs of $51.76 per acre[16] *(Chart 9)* .

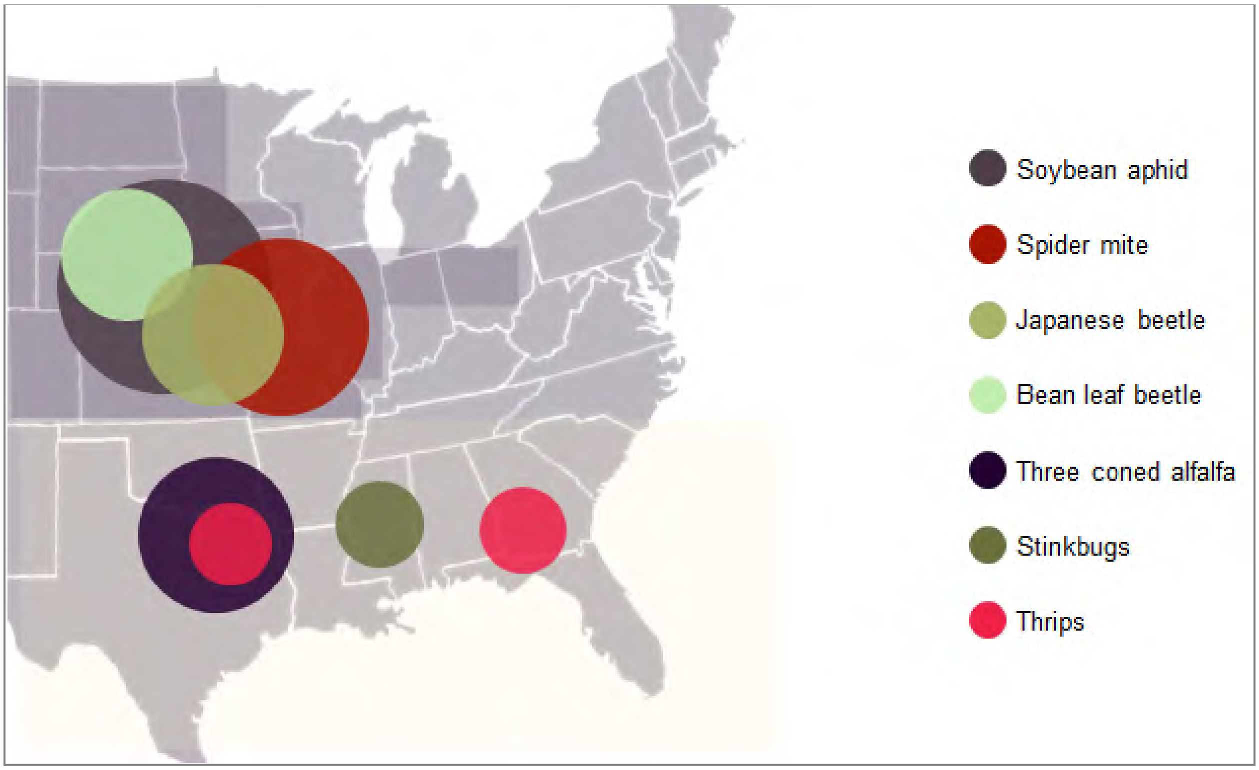

Chart 9: Main insect pressures by region

In this section we'll cover Soybean Aphids, Spider Mite, Japanese Beetle, and Bean Leaf Beetle.

Soybean Aphids became a major problem in the 2000s. While aphid damage to soybean begins with the sucking of plant juices, continuous feeding through the pod filling stage results in the plant's decreased seed production of up to 50%.[17] Similarly, late-season podworms begin their feeding on foliage as larvae in late July, and as pods form, larvae will continue to feed on pods. Currently there are recommended soybean aphids thresholds that have prevented losses of at least $40.00 per acre, creating $886 million of incremental yield for American farmers. Despite economic threshold guidelines, prophylactic insecticide seed treatment and prophylactic foliar sprays have been widely used against soybean aphid, resulting in negative returns for farmers that spray below the thresholds.

Spider mite feeding also reduces pod set and increases risk of pod shatter during the critical pod development stages. Yield loss can be as high as 40%. Scouting for spider mites requires

[16] https://www.nimss.org/projects/view/mrp/outline/14636

[17] https://www.dekalbasgrowdeltapine.com/en-us/agronomy/managing-late-season-soybean-issues.html

incredible attention to detail, often requiring a magnifying glass to notice their presence on the undersides of leaves.[18] Symptoms will eventually appear as white, yellow, or brown specks. Careful application of insecticides according to threshold is recommended to prevent the worsening of population flares.[19]

Japanese beetles can reduce yield by 17%. Furthermore, their eggs are normally not visible, so detecting the onset of Japanese beetles is nearly impossible. Growers rely on visual damage to note their arrival, which requires the systematic process of scanning all parts of the sampled plants, since Japanese beetles tend to aggregate.[20] Detection of Japanese beetles is even further complicated by other insects that resemble them, namely the false Japanese beetles (including masked chafers and May or June beetles)[21]. Once defoliation is visible, significant yield loss will occur (Chart 10).

Estimated soybean yield loss from defoliation

Stage	Defoliation (% Leaf Area)		
	50	**70**	**100**
		% Yield loss	
R1-R2	6	9	23
R4	12	22	56
R5	17	31	75
R6	14	23	53

Chart 10: Yield loss vs. defoliation

The damage done by bean leaf beetles spreads across the eastern ⅔ of the United States. Adult feeding on seedling shoot tissue can reduce yield by 12%, not including the loss due to viruses they impart.[22]

Plant sensors will alleviate the questions of where and when to sample. By constantly monitoring the whole field, all plants become part of the sample. Crop based detection platforms for insect infestations can therefore generate similar benefits with additional advantages such as a more optimized scouting schedule that can help farmers reduce their costs and reduce the reliance on scarce labor.

[18] https://extension.umn.edu/pest-management/twospotted-spider-mites-soybean

[19] https://extension.umn.edu/soybean-pest-management/managing-spider-mite-soybean#when-to-spray-spider-mites-1433461

[20] https://extension.umn.edu/soybean-pest-management/japanese-beetle-soybean

[21] https://ipm.missouri.edu/pestmonitoring/jb/identification.cfm

[22] https://doi.org/10.1093/jipm/pmx028

Section IV: Conclusions

A lack of reliable methods to detect specific pathogens early costs US farmers $5.5B annually is yield loss and an additional $2B annually on pesticide and other pest management practices. The best agronomic tools can only detect general stress after significant damage has occurred, which offers no compelling value to farmers. In addition, many of these tools require changes to current operations or farmer involvement resulting in a challenging barrier to entry. Scouting labor is scarce and requires better allocation in order to increase coverage of large fields.

InnerPlant is the first *plant-centric farming platform* that provides specific detection of stresses within emergence (weeks before other methods). Enabling crops to express their needs will create value in 3 ways:

1. Increasing yields by reducing crop losses to pest and diseases
2. Reducing costs by optimizing pesticide applications, spraying only when needed, and improving efficiency of scouting labor
3. Reducing overall risk for a large farming operation, with each plant expressing data