The global burden of pathogens and pests on major food crops

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Outline

The challenge of assessing the state of crop health globally

Conducting an expert-based assessment of crop health

Estimates of crop losses by pathogen & pest

Towards a global surveillance system for crop health

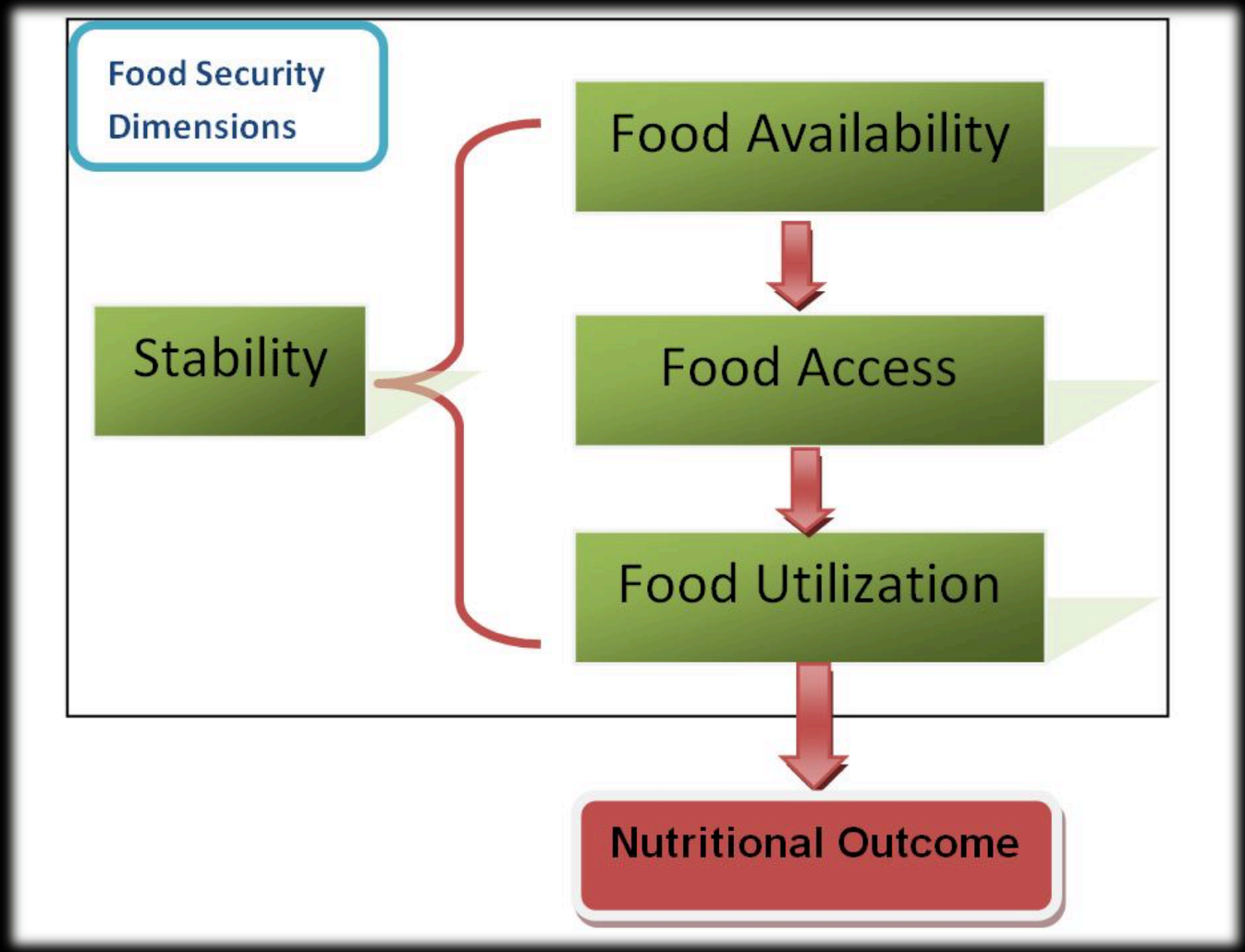
The challenge of assessing the global state of crop health

Pexels

The impact of P&Ps on food security

Crop pathogens and pests (P&Ps) reduce the yield and quality of agricultural production

They affect all components of food security

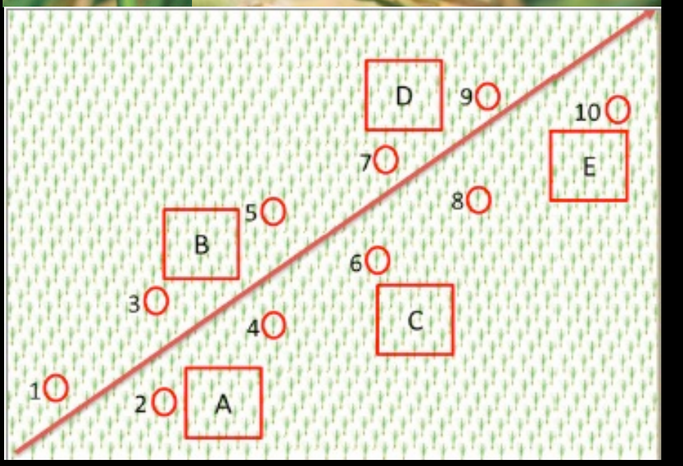


Savary, S. et al. Crop health and its global impacts on the components of food security. Food Security 9, 311–327 (2017)
FAO, IFAD & WFP. The State of Food Insecurity in the World 2013. The Multiple Dimensions of Food Security. (FAO, 2013)

The challenges of obtaining reliable yield loss data

Generating reliable, quantitative data on the importance of crop P&Ps is a major challenge due to

- A wide diversity of organisms
- A diversity of cultivated crops
- The range of agricultural settings in the biosphere
- The regular emergence and re-emergence of P&Ps
- The difficulty of impact quantification in itself



Esker, P., Savary, S. & McRoberts, N. Crop loss analysis and global food supply: focusing now on required harvests. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources 7, (2012)

Savary, S., Teng, P. S., Willocquet, L. & Nutter, F. W. Quantification and modeling of crop losses: a review of purposes. Annual Review of Phytopathology 44, 89–112 (2006).

CABI. Crop Protection Compendium. (CAB International, Wallingford, UK, 2018)

Paini, D. R. et al. Global threat to agriculture from invasive species. Proceedings of the National Academy of Sciences 113, 7575–7579 (2016)

Previous efforts to estimate yield loss and their drawbacks

Figures of worldwide crop losses have been derived from pesticide field trials (e.g. *Oerke (2006) 21% - wheat, 27% - rice, 21% - maize, 32% - potato, 19% - soybean).*
The representativeness of the pesticide trial approach may have drawbacks:

- Over time
- Over space
- Across scale
- Of injury




The global burden of P&Ps on major food crops remains poorly quantified

Oerke, E. C. Crop losses to pests. Journal of Agricultural Science 144, 31–43 (2006)
Oerke, E. C., Dehne, H. W., Schönbeck, F. & Weber, A. Crop Production and Crop Protection - Estimated Losses in Major Food and Cash Crops. (Elsevier Science, 1994)
Cramer, H. H. Plant protection and world crop production. Pflanzenschutz-Nachrichten 'Bayer' 20, 1–524 (1967)
Savary, S., Elazegui, F. A. & Teng, P. S. Assessing the representativeness of data on yield losses due to rice diseases in tropical Asia. Plant Disease 82, 705–709 (1998)

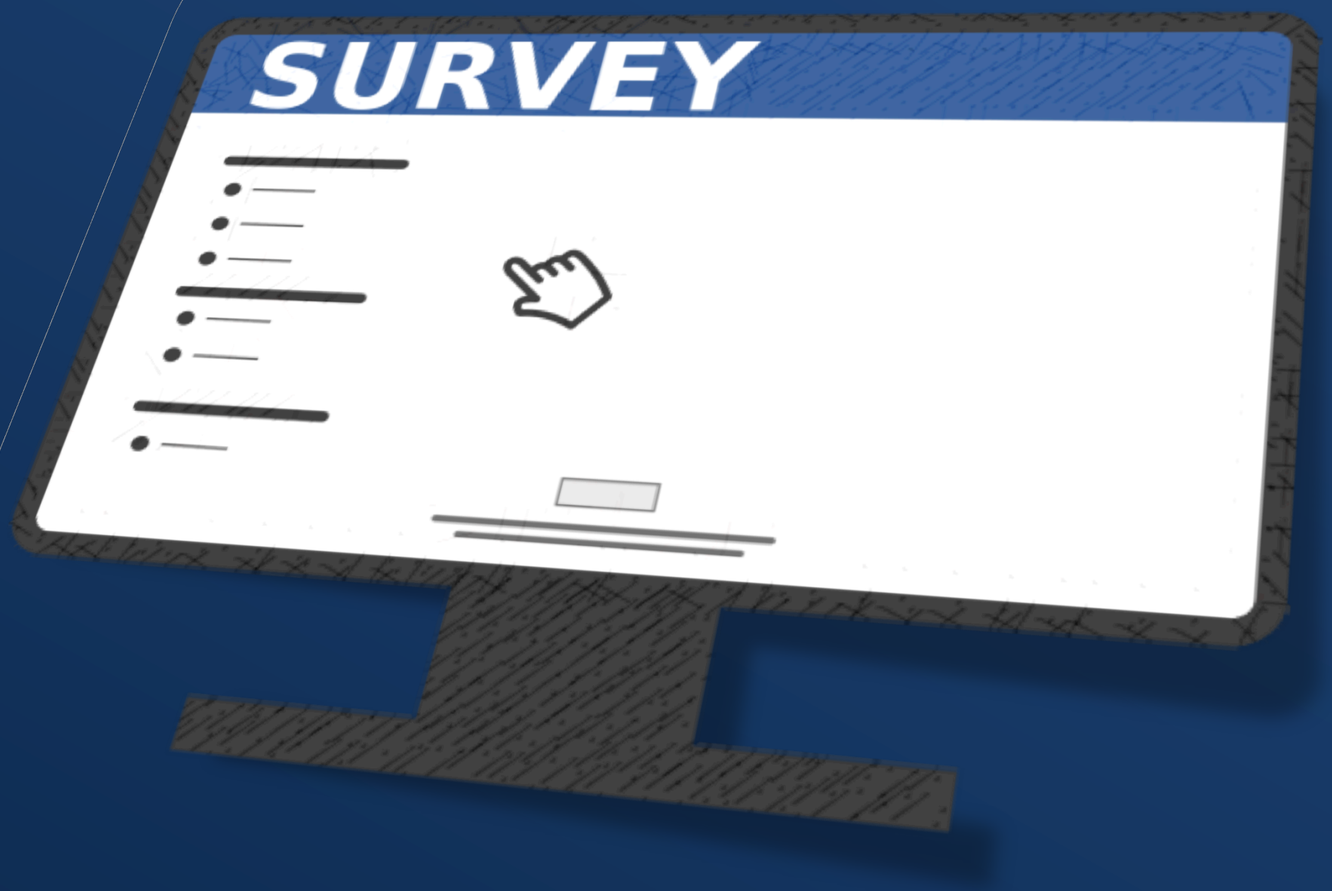
A different approach to assess crop health globally

We aimed to quantify yield losses associated with P&Ps on five key food crops in the world; wheat, rice, maize, potato and soybean; ~50% of global human calorific intake.

We did this by:

- Using expert information on location, magnitude and frequency of losses
- Cross checking survey responses against publications and databases
- Identifying associations between crop losses and geography, climate and yield
- Estimating crop losses per P&P, globally and by food security hotspot
- Estimating losses per crop, globally and by food security hotspot

Conducting an expert-based assessment of crop health



Designing the online survey

We designed an online survey for crop health experts to obtain expert assessments of crop losses for five major crops across the world

- We requested inputs on disease or pest injuries
- We collected information on location, P&P name, magnitude and level of losses

The survey (http://globalcrophealth.org) was conducted for three months between 1st November 2016 and 31st January 2017

This global expert survey is the first of its kind for crop health assessment

ISPP. International Newsletter on Plant Pathology. 46(11) http://www.isppweb.org/newsletters/pdf/46_11.pdf

The survey questions

Approximate location of report

Expert Assessment on Global Wheat Health

1) Move the red marker to the approximate location where the pest or disease occurred. You can also zoom in and/or type the name of the location.

P&P you are reporting on

2) Pest/disease name *

Septoria (Zymoseptoria) tritici blotch

- Septoria (Zymoseptoria) tritici blotch
- Stagonospora nodorum blotch
- Leaf (brown) rust
- Stem (black) rust
- Stripe (yellow) rust
- Fusarium head blight – Scab
- Tan spot
- Spot blotch
- Barley yellow dwarf (BYD)
- Aphids
- Other

Loss frequency

3) Frequency of losses *

- ○ Does not occur
- ○ Every season
- ● Every other season
- ○ One season in five
- ○ Less frequent than one season in five

Select the option that best represents the frequency

Loss magnitude

4) Level of yield losses *

- ○ < 1% (less than 1%)
- ○ 1 - 5%
- ● 5 - 20%
- ○ 20 - 60%
- ○ > 60% (more than 60%)

Select the option that best represents the loss

Respondent info

5) Your full name

To acknowledge your contribution in any report from this survey

6) Your email

You will receive a copy of your responses

7) Your institute

To acknowledge your institute in any report from this survey

The response

The survey was circulated to the ISPP mailing list (covering over 2,500 members), over 60 associated societies (covering over 26,000 members) and to experts in our scientific networks

Progress on the survey was featured in the ISPP newsletter and in *Nature*

We obtained responses from **219 crop health experts**
who submitted **989 individual reports**
covering **137 pathogens and pests**
across **67 countries**

ISPP. International Newsletter on Plant Pathology. 46(12) http://www.isppweb.org/newsletters/pdf/46_12.pdf
ISPP. International Newsletter on Plant Pathology. 47(1) http://www.isppweb.org/newsletters/pdf/47_1.pdf
ISPP. International Newsletter on Plant Pathology. 47(4) http://www.isppweb.org/newsletters/pdf/47_4.pdf
Nelson, A. D. et al. Crop pests: Crop-health survey aims to fill data gaps. Nature 541, 464 (2017)

The coverage of pathogens and pests

The 137 reported pathogens and pests were compared against information in the CABI Crop Protection Compendium and around 100 other literature sources

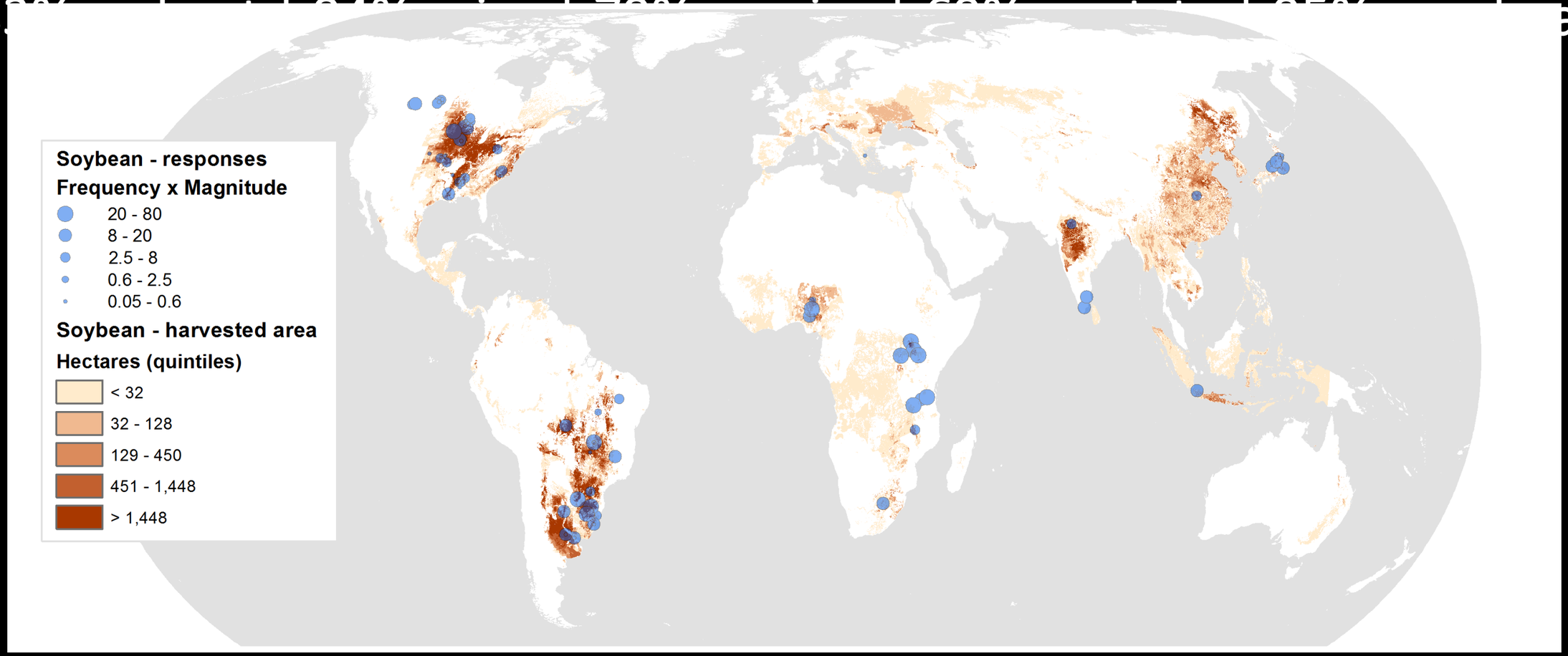
	Wheat	Rice	Maize	Potato	Soybean
Reports	326	247	138	154	125
P&Ps	31	26	38	17	25
Countries	35	36	20	31	16

We did not identify any omissions of major P&Ps in the survey responses

CABI. *Crop Protection Compendium*. (CAB International, Wallingford, UK, 2018)
Bockus, W. W., Bowden, R. L., Hunger, R. M., Murray, T. D. & Smiley, R. W. Compendium of Wheat Diseases and Pests. (APS Press, 2010)
Wiese, M. V. Compendium of Wheat Diseases. (APS Press, 1987)
Ou, S. H. Rice Diseases. (CABI, 1985)
Pathak, M. D. Insect Pests of Rice. (IRRI, 1977)
White, D. G. Compendium of Corn Diseases. (APS Press, 1999)
Stevenson, W. R., Loria, R., Franc, G. D. & Weingartner, D. P. Compendium of Potato Diseases. (APS Press, 2001)
Hartman, G. L. et al. Compendium of Soybean Diseases and Pests. (APS Press, 2015)

The geographic coverage of survey responses

The 67 countries account for 84% of global production (FAOSTAT, 2000-2014 averages)



http://www.fao.org/faostat/en/#data/QC

The magnitude and frequency of reported losses

% of responses		Loss frequency				
		Chronic	Frequent	Infrequent	Rare	*Total*
Loss magnitude	High					
	Moderate					
	Low					
	Very low					
	Total					

The magnitude and frequency of reported losses

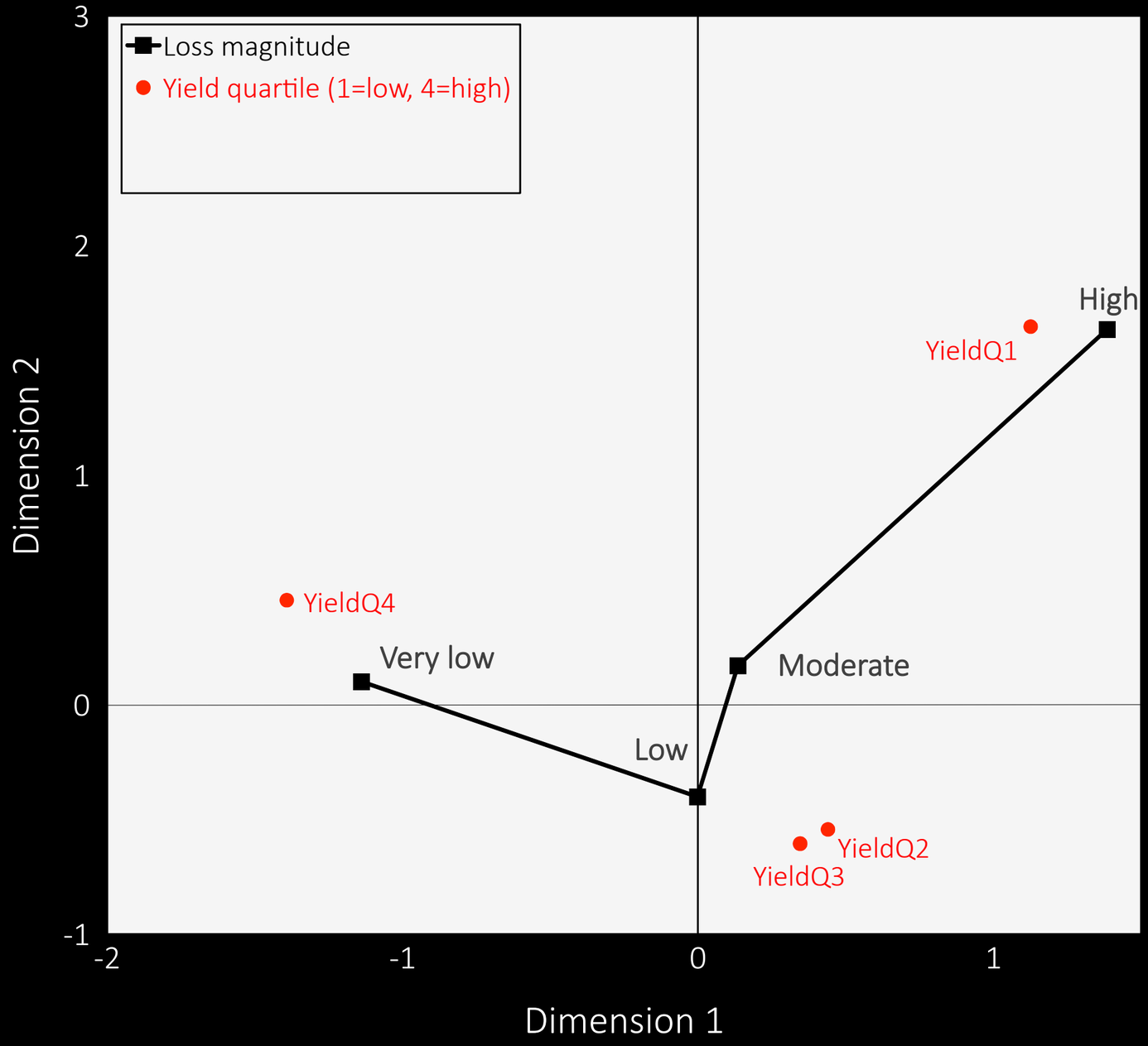
% of responses		Loss frequency				
		Chronic	Frequent	Infrequent	Rare	*Total*
Loss magnitude	High	10	2	1	1	*14*
	Moderate	25	5	3	1	*34*
	Low	27	6	3	1	*37*
	Very low	8	2	2	3	*15*
	Total	*70*	*15*	*9*	*6*	*100*

The magnitude and frequency of reported losses

% of responses		Loss frequency				
		Chronic	Frequent	Infrequent	Rare	*Total*
Loss magnitude	High	10	2	1	1	*14*
	Moderate	25	5	3	1	*34*
	Low	27	6	3	1	*37*
	Very low	8	2	2	3	*15*
	Total	*70*	*15*	*9*	*6*	*100*

70% of reports indicated chronic losses (occur every growing season)
Around 50% indicated that losses were moderate or high
35% of reports indicated that losses were both chronic and moderate/high.

Association of losses with yield, climate and food security



<u>Correspondence analysis plot for rice</u>

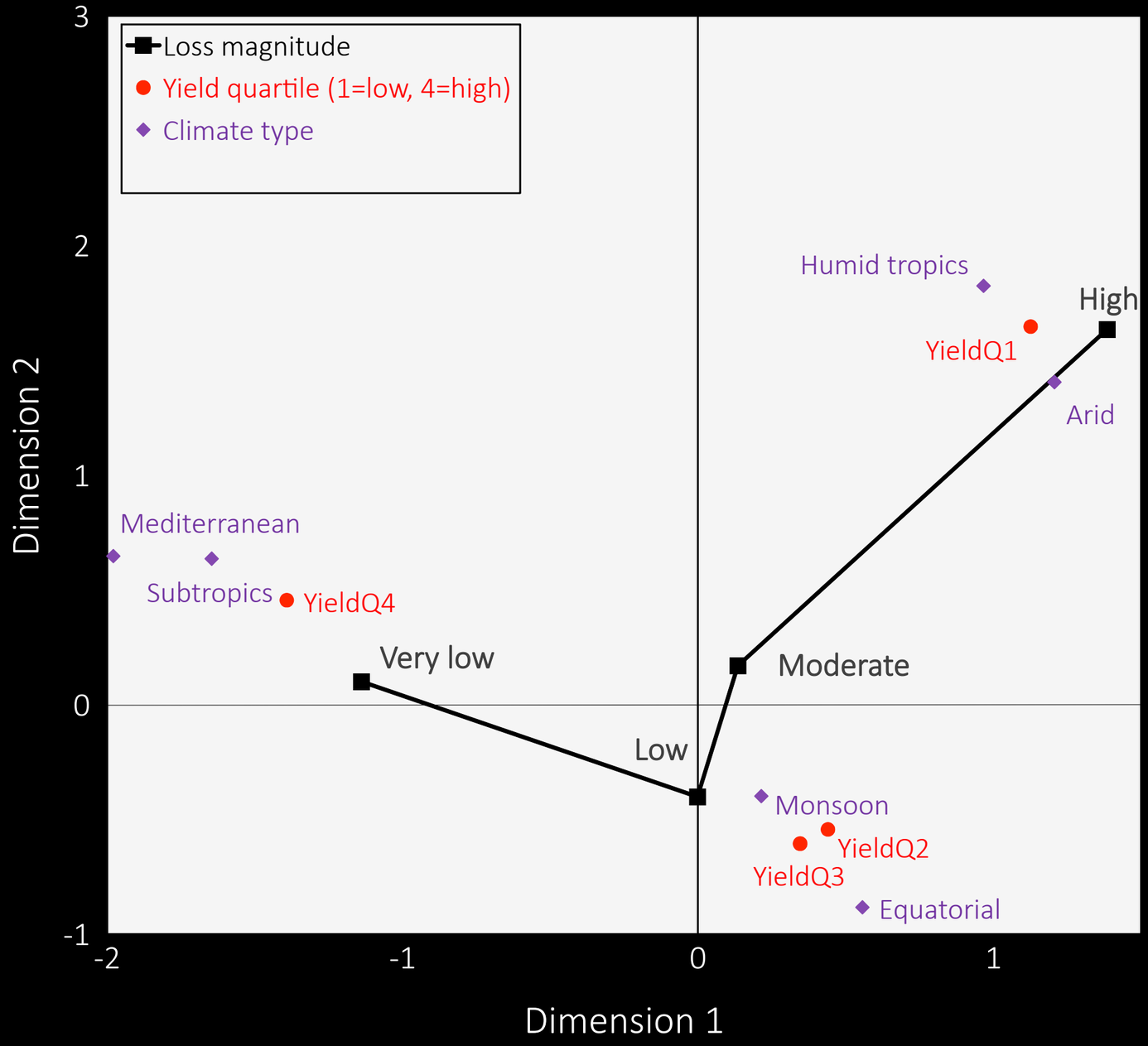
Multivariate analysis of associations between categorized variables.

Proximity between variables indicates association. The significance of the association is related to the squared distance from

For rice yield losses and yield performance

- There is a clear path of increasing levels of reported loss magnitudes
- There is a consistent, negative association between reported losses and yield (agricultural performance)

Association of losses with yield, climate and food security



<u>Correspondence analysis plot for rice</u>

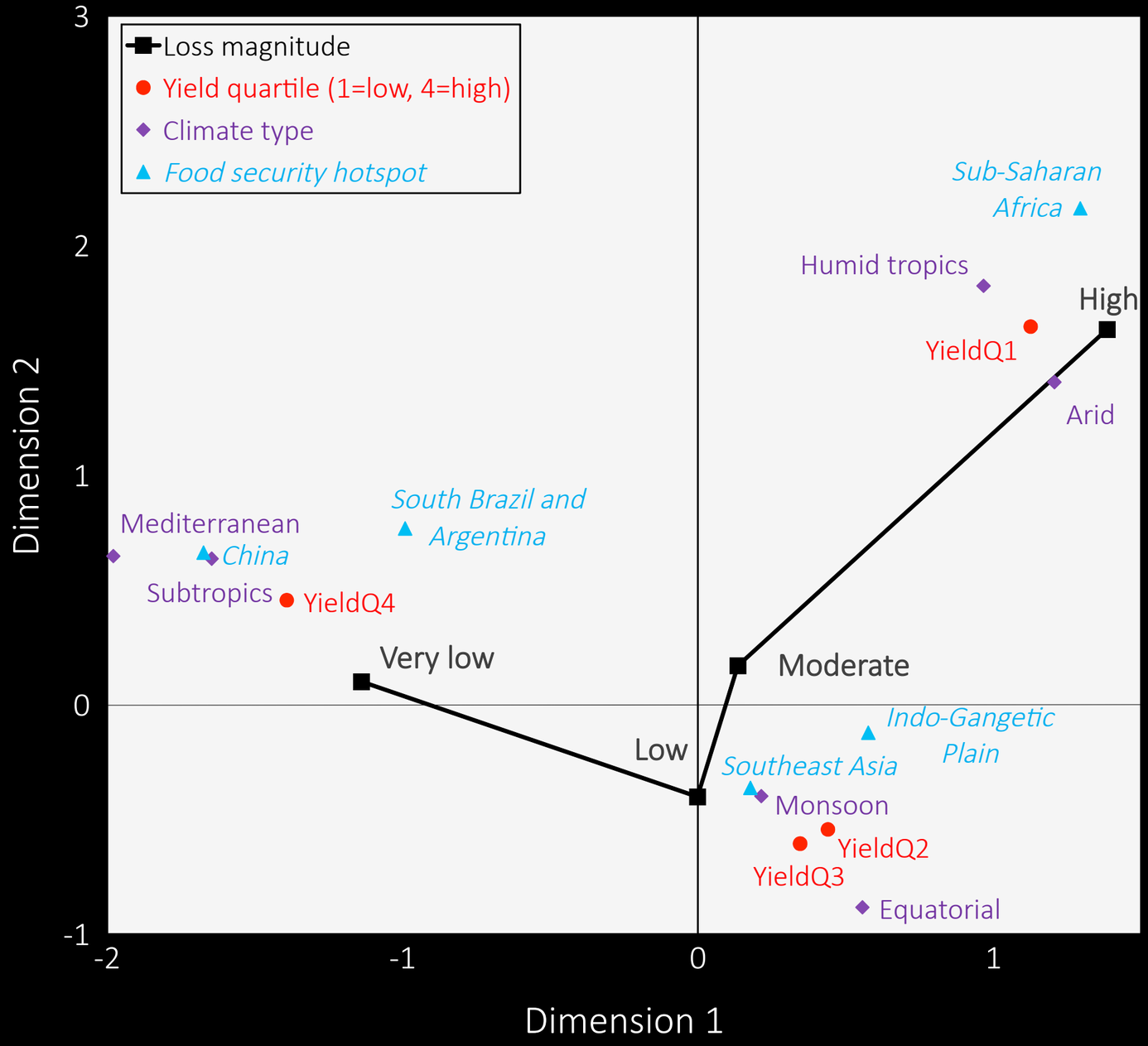
Multivariate analysis of associations between categorized variables.

Proximity between variables indicates association. The significance of the association is related to the squared distance from

For rice yield losses and climate

- The humid topics and arid climates are associated with high reported losses
- Monsoonal and equatorial climates are associated with moderate to low reported losses

Association of losses with yield, climate and food security

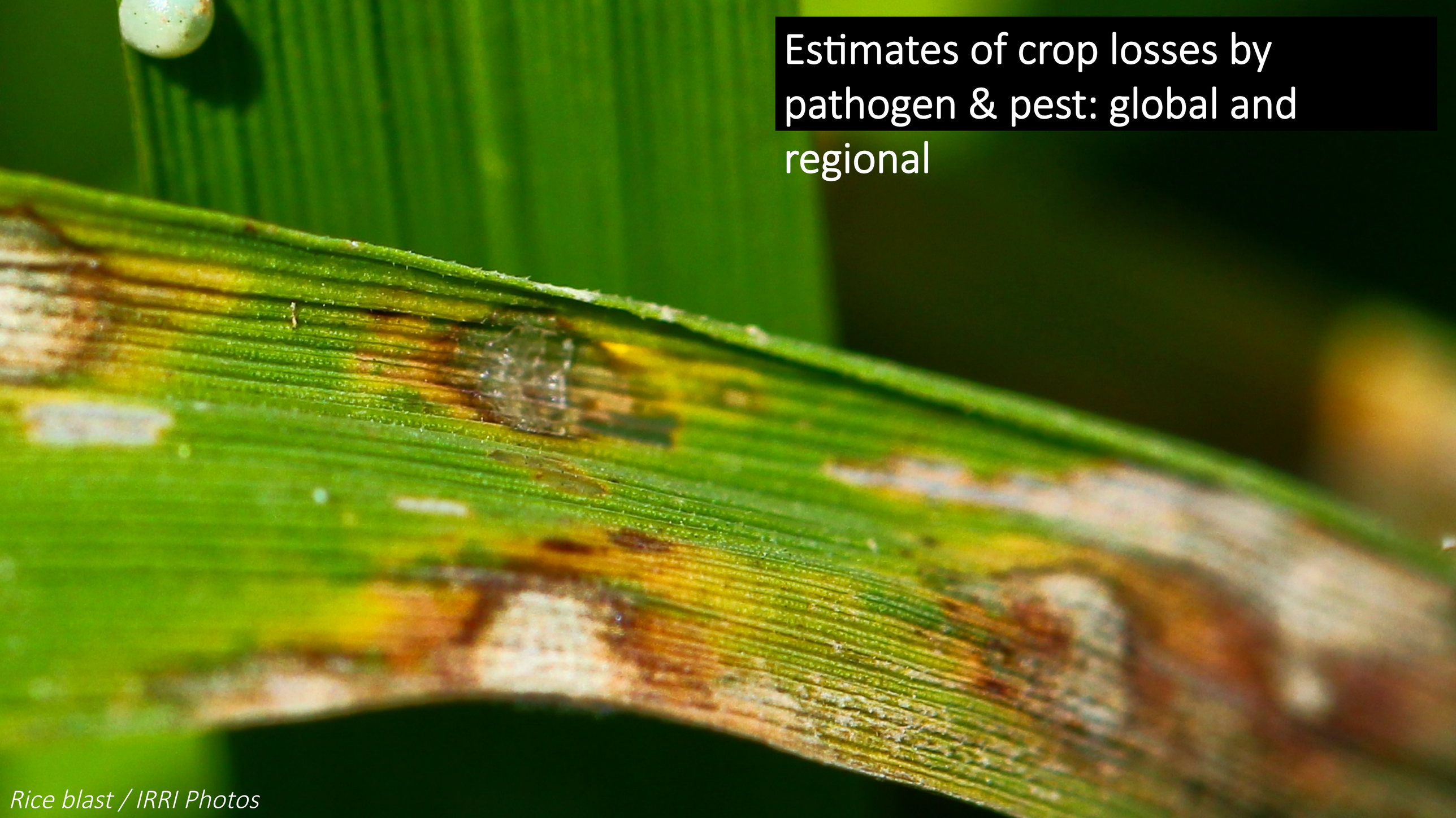


<u>Correspondence analysis plot for rice</u>

Multivariate analysis of associations between categorized variables. *Proximity between variables indicates association. The significance of the association is related to the squared distance from*

For rice yield losses and FS hotspots

- the highest reported losses are associated with Sub Saharan Africa
- moderate and low reported losses are associated Southeast Asia and the Indo-Gangetic Plain
- China and Brazil are associated with very low reported losses



Estimates of crop losses by pathogen & pest: global and regional

Rice blast / IRRI Photos

Estimates of crop losses per P&P

For each P&P

(1) We computed FMc, the average loss Frequency × loss Magnitude per country *(one FMc value for every P&P x country combination)*

(2) We used the mean FMc for countries that reported the P&P in the literature but which were not reported in the survey

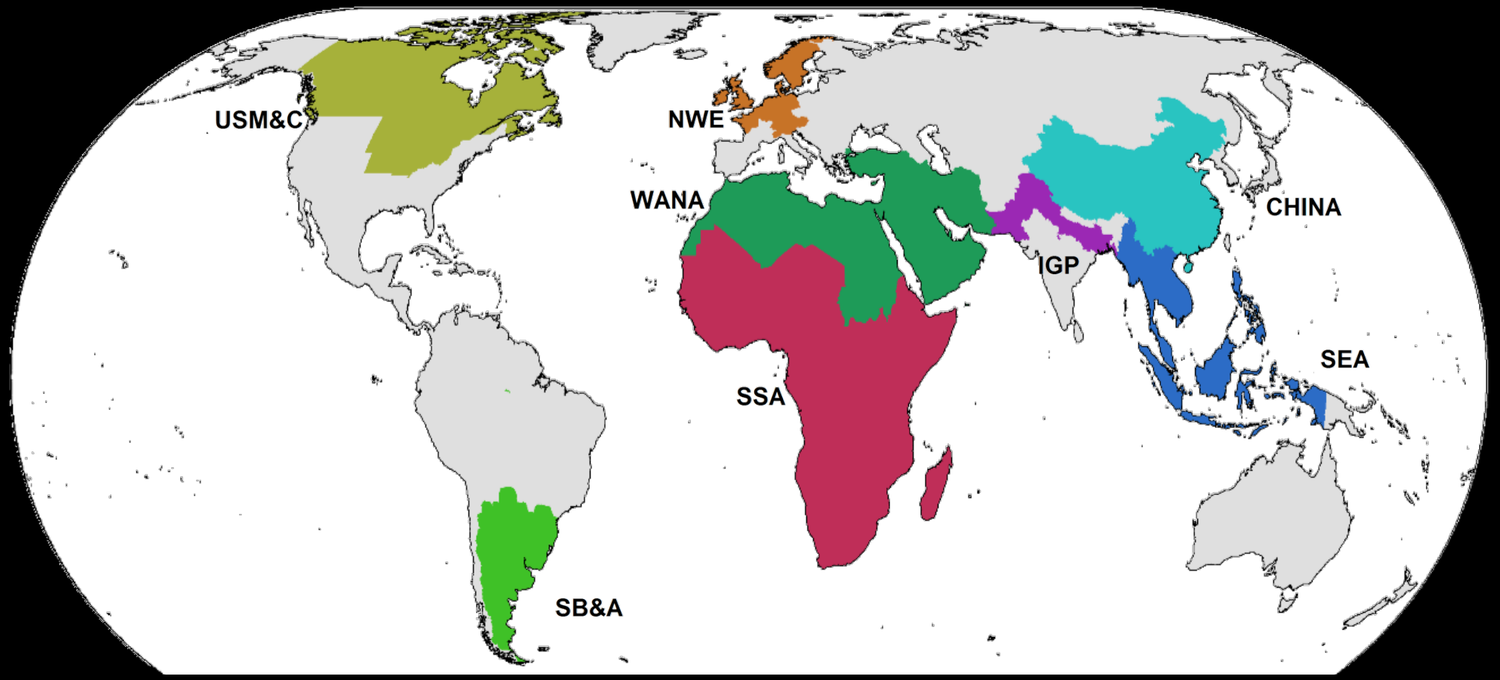
(3) We weighted FMc by the crop production of each country *(bigger production = bigger contribution to regional/global loss)*

(4) We weighted FMc based on spatial extent and landscape diversity as reported in the literature

Estimates of crop losses per P&P – globally and regionally

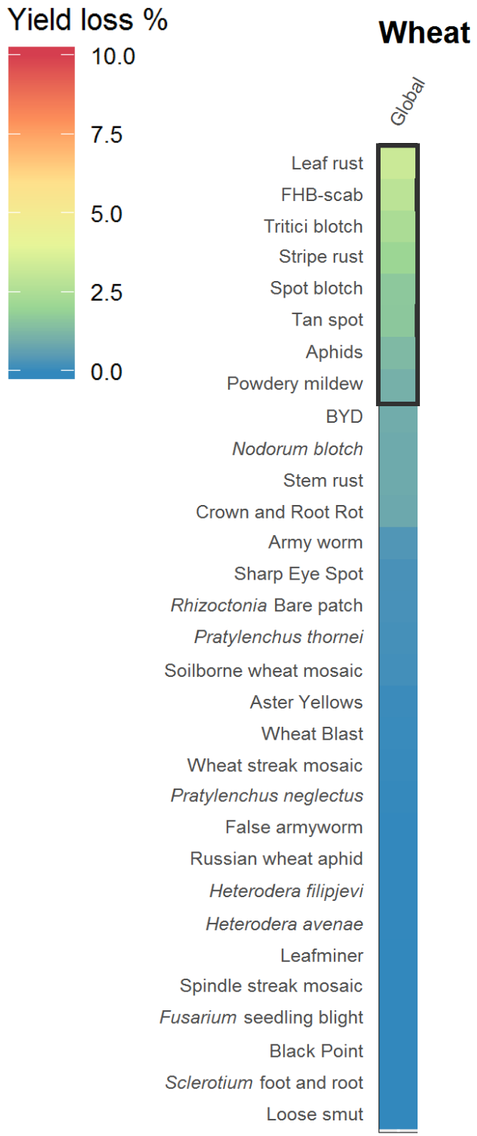
Crop loss estimates per P&P by food security hotspots

- We used FAO data on production, consumption, exports and imports to identify eight food security regions which are food sources and/or sinks
- We estimated losses per P&P globally and for each hotspot



1 **USM&C** = US Midwest and Canada
2 **SB&A** = South Brazil, Paraguay, Uruguay and Argentina
3 **NWE** = Northwest Europe
4 **WANA** = West Asia and North Africa 5 **CHINA** = Mainland China
6 **SEA** = Southeast Asia
7 **SSA** = Sub-Saharan Africa
8 **IGP** = Indo-Gangetic Plains

Estimates of wheat losses – by pathogen and pest

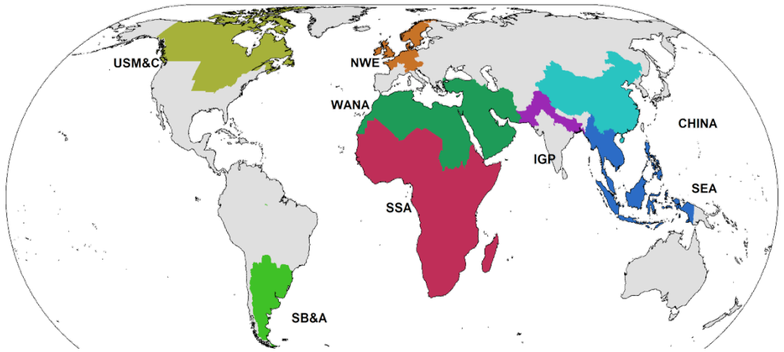


31 P&Ps reported in wheat

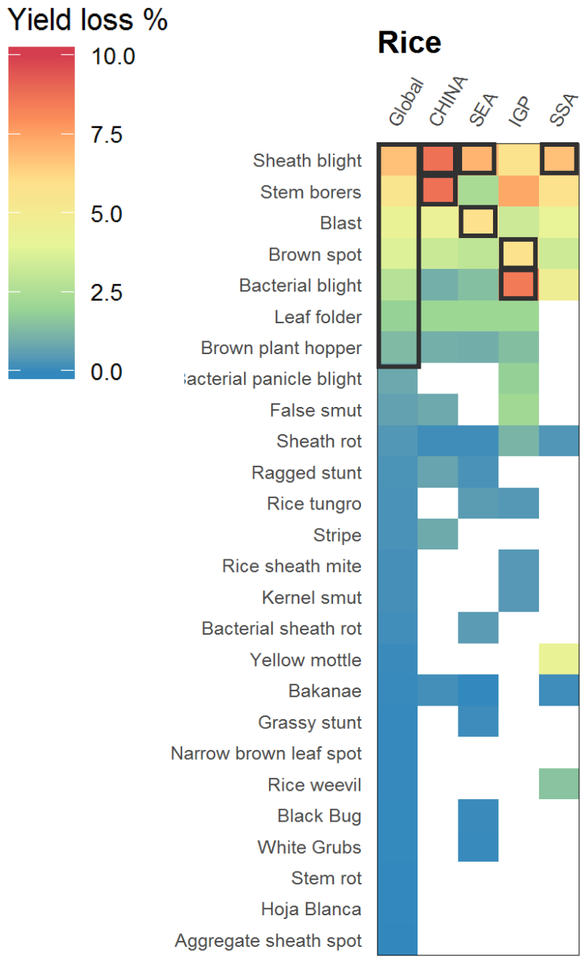
Eight caused losses higher than 1% globally (leaf rust, Fusarium head blight-Scab, tritici blotch, stripe rust, spot blotch, tan spot, aphids, and powdery mildew)

Across food security hotspots, crop losses are highest to

- tan spot (4.3%) and FHB-scab (3.2%) in USM&C
- tan spot (6.8%) and wheat blast (3.5%) in SB&A
- FHB-scab (8.8%) in CHINA
- spot blotch (7.3%) in IGP
- stem rust (8.9%) in SSA



Estimates of rice losses – by pathogen and pest



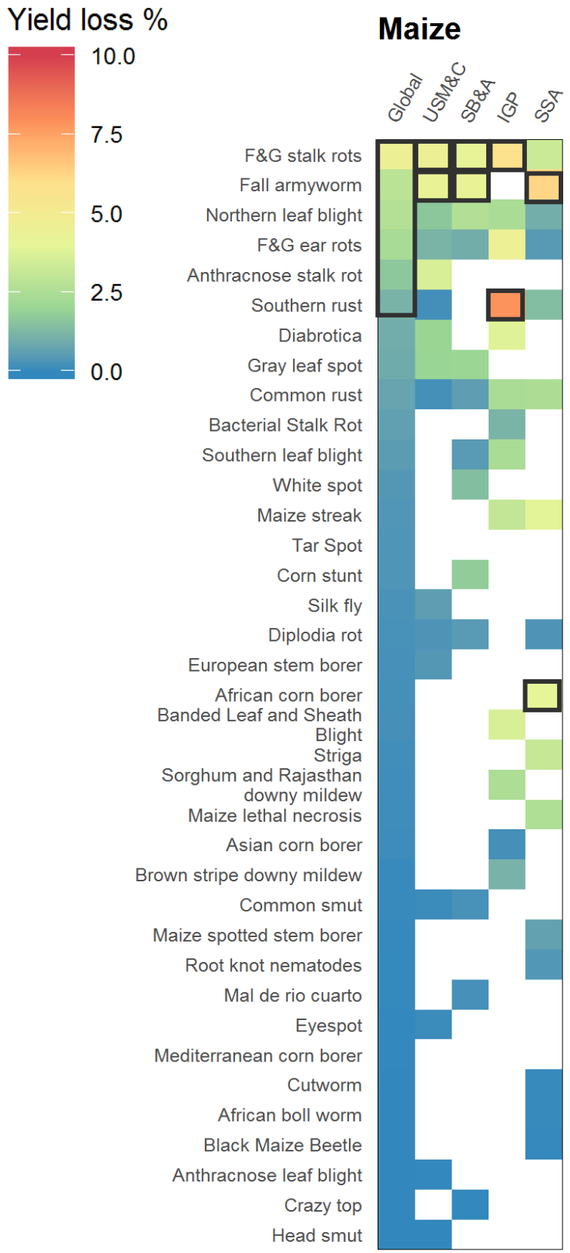
26 P&Ps reported in rice

Seven caused losses higher than 1% globally (sheath blight, stem borers, blast, brown spot, bacterial blight, leaf folder, and brown plant hopper)

Across food security hotspots, crop losses are highest to

- sheath blight (8.8%) and stem borers (8.8%) in CHINA
- sheath blight (7.1%) and blast (5.9%) in SEA
- brown spot (5.9%) and bacterial blight (8.5%) in IGP
- sheath blight (6.8%) in SSA

Estimates of maize losses – by pathogen and pest



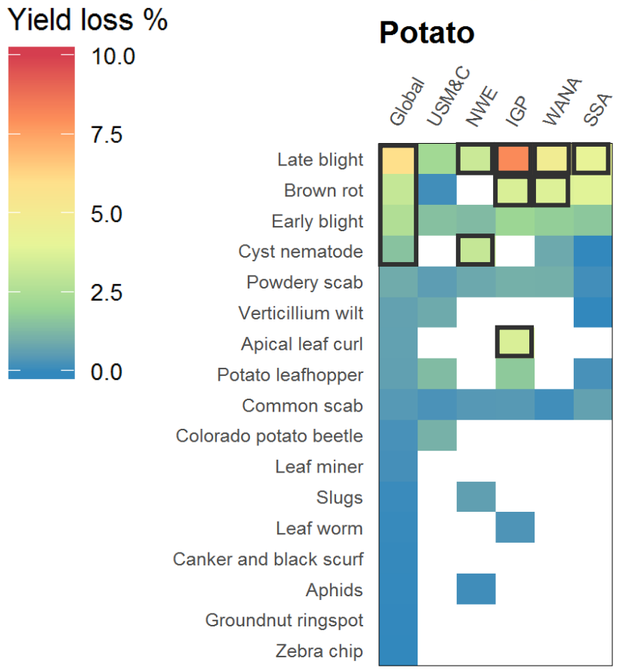
38 P&Ps reported in maize

Six caused losses higher than 1% globally (Fusarium and Gibberella stalk rots, fall armyworm, northern leaf blight, Fusarium and Gibberella ear rots, anthracnose stalk rot, and southern rust)

Across food security hotspots, crop losses are highest to

- Fusarium and Gibberella (F&G) stalk rots (4.5%) and fall armyworm (4.3%) in USM&C
- fall armyworm (4.3%) and F&G stalk rots (4.2%) in SB&A
- southern rust (7.9%) and F&G stalk rots (5.8%) in IGP
- fall armyworm (6.3%) and African corn borer (4.0%) in SSA

Estimates of potato losses – by pathogen and pest



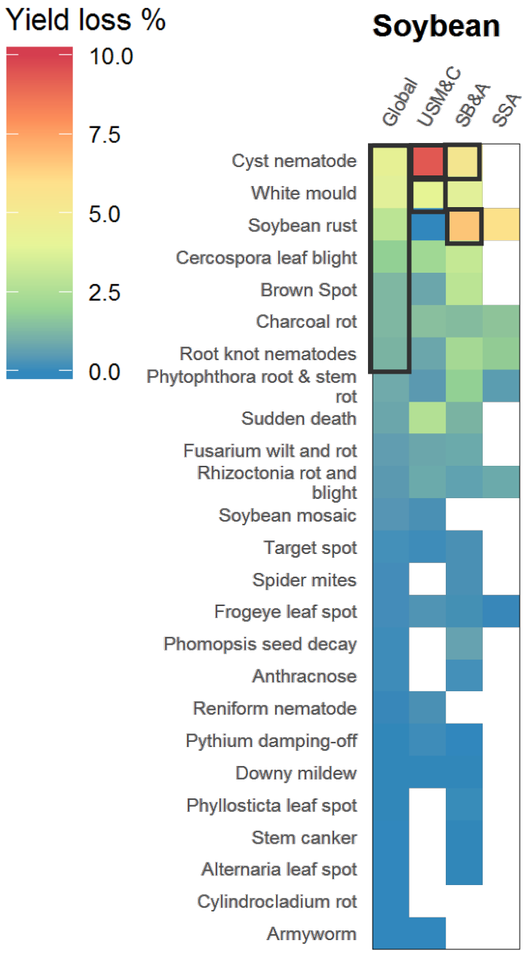
17 P&Ps reported in potato

Four caused losses higher than 1% globally (late blight, brown rot, early blight, and cyst nematode)

Across food security hotspots, crop losses are highest to

- late blight (3.2%) and cyst nematode (3.1%) in NWE
- late blight (8.1%), apical leaf curl (3.7%), and brown rot (3.6%) in IGP
- late blight (4.9%) and brown rot (3.8%) in WANA
- late blight (4.2%) and brown rot (3.9%) in SSA

Estimates of soybean losses – by pathogen and pest



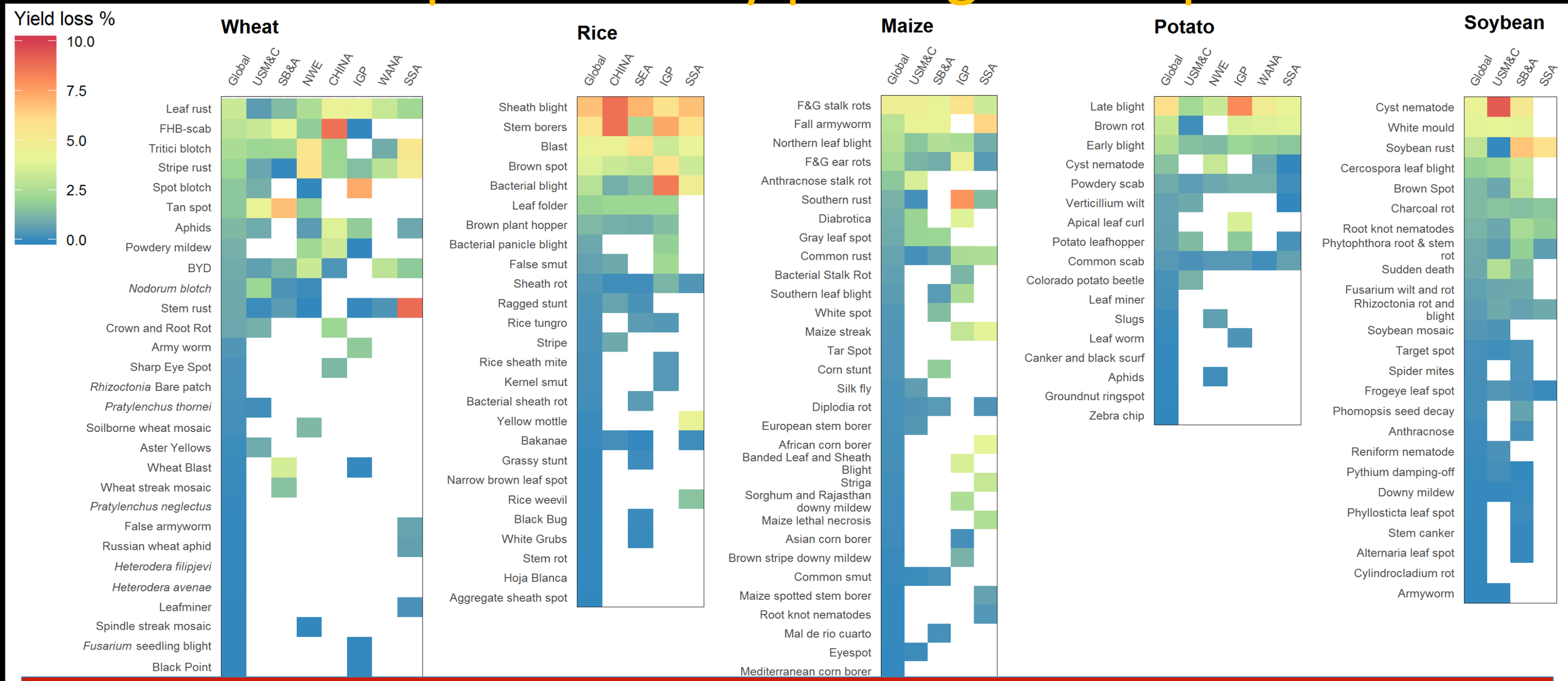
25 P&Ps reported in soybean

Seven caused losses higher than 1% globally (cyst nematode, white mould, soybean rust, Cercospora leaf blight, brown spot, charcoal rot, and root knot nematodes).

Across food security hotspots, crop losses are highest to

- cyst nematode (9.3%) and white mould (4.1%) in USM&C
- soybean rust (6.7%) and cyst nematode (5.2%) in SB&A

Estimates of crop losses – by pathogen and pest

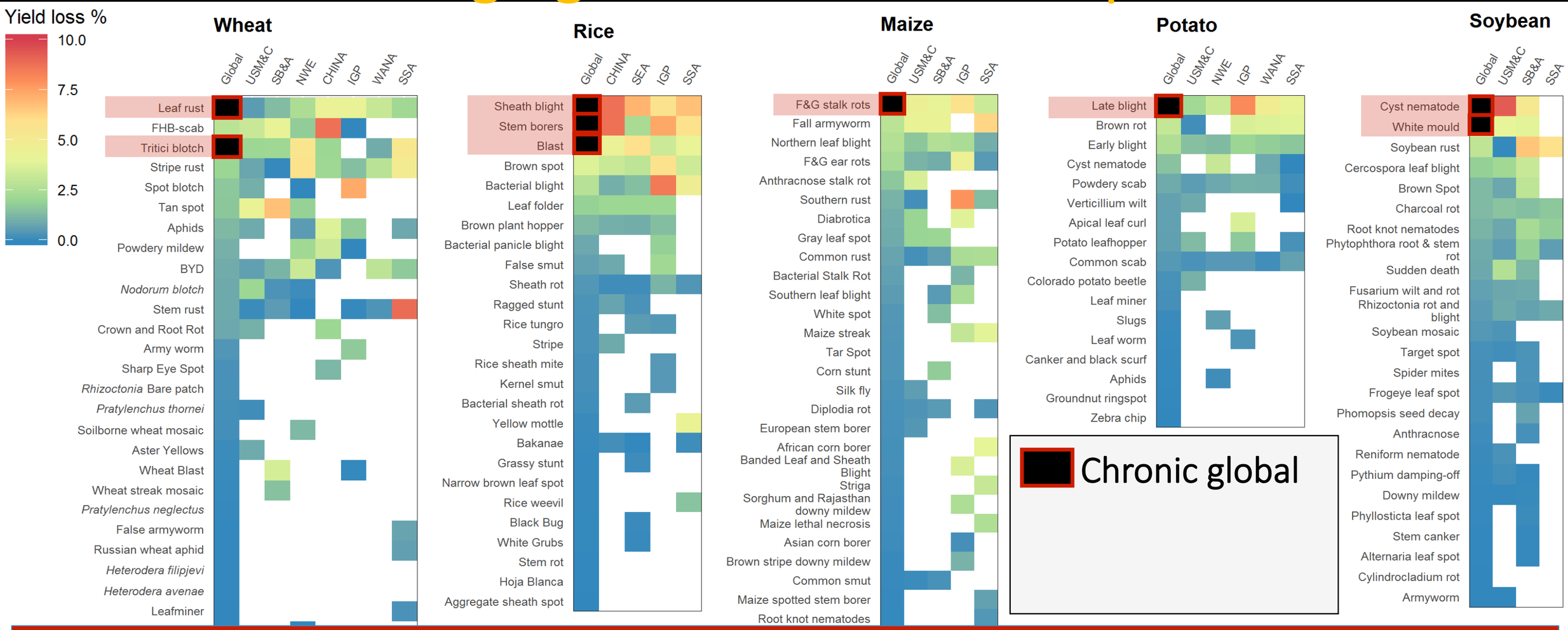


137 P&Ps were reported with a large variation in crop losses caused by specific P&Ps. The relative importance of P&Ps varied across food security hotspots

Estimates of crop losses – by pathogen and pest

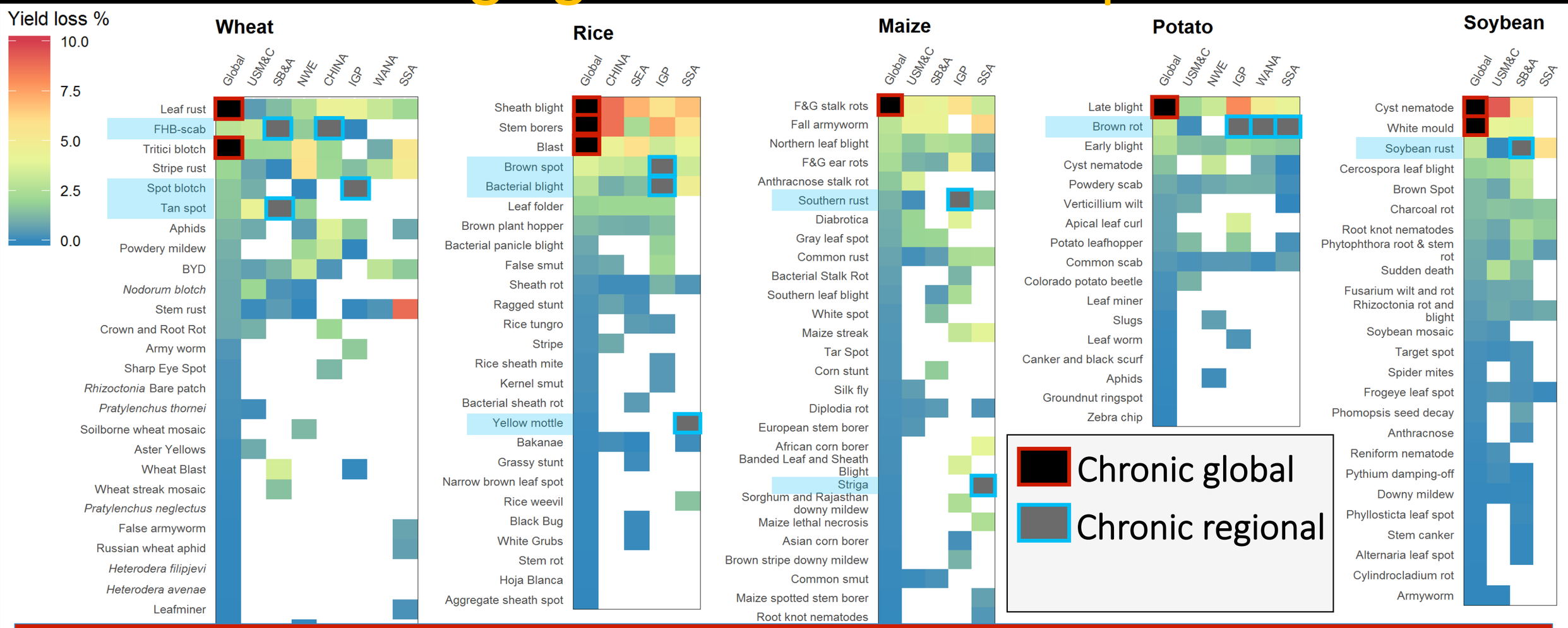
137 P&Ps were reported with a large variation in crop losses caused by specific P&Ps. The relative importance of P&Ps varied across food security hotspots

Chronic and emerging P&Ps – a basis for prioritisation?



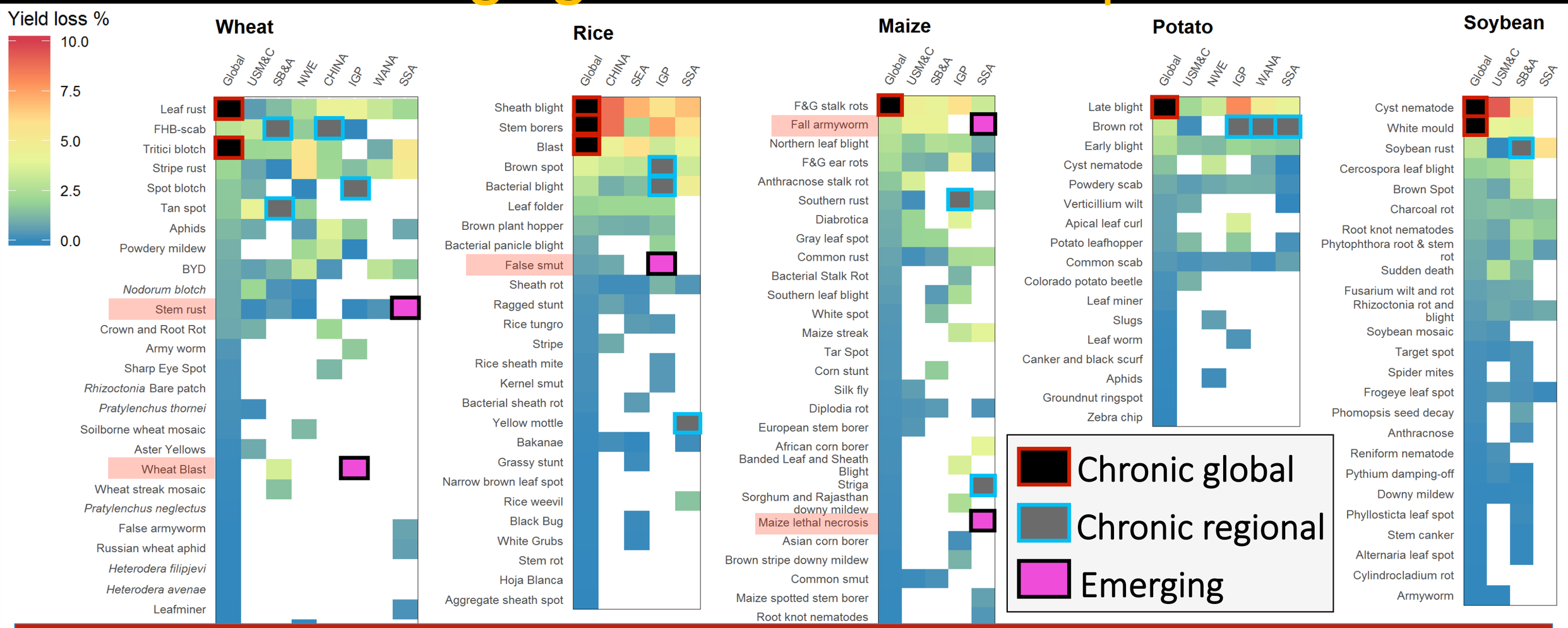
P&Ps that chronically cause large crop losses globally require global efforts to deliver more efficient & sustainable management tools, such as varieties with durable resistance

Chronic and emerging P&Ps – a basis for prioritisation?



P&Ps that chronically cause large crop losses in specific food security hotspots require similar efforts - such as improved host plant resistance - but with the challenge of many pervasive abiotic limiting factors in several of these hotspots

Chronic and emerging P&Ps – a basis for prioritisation?



Emerging P&Ps with large regional increases in crop losses require urgent action based on knowledge of the biology of the P&P. Efforts to generate long term solutions - such as varietal resistance - need to be undertaken rapidly

Estimates of crop losses per crop – globally and regionally

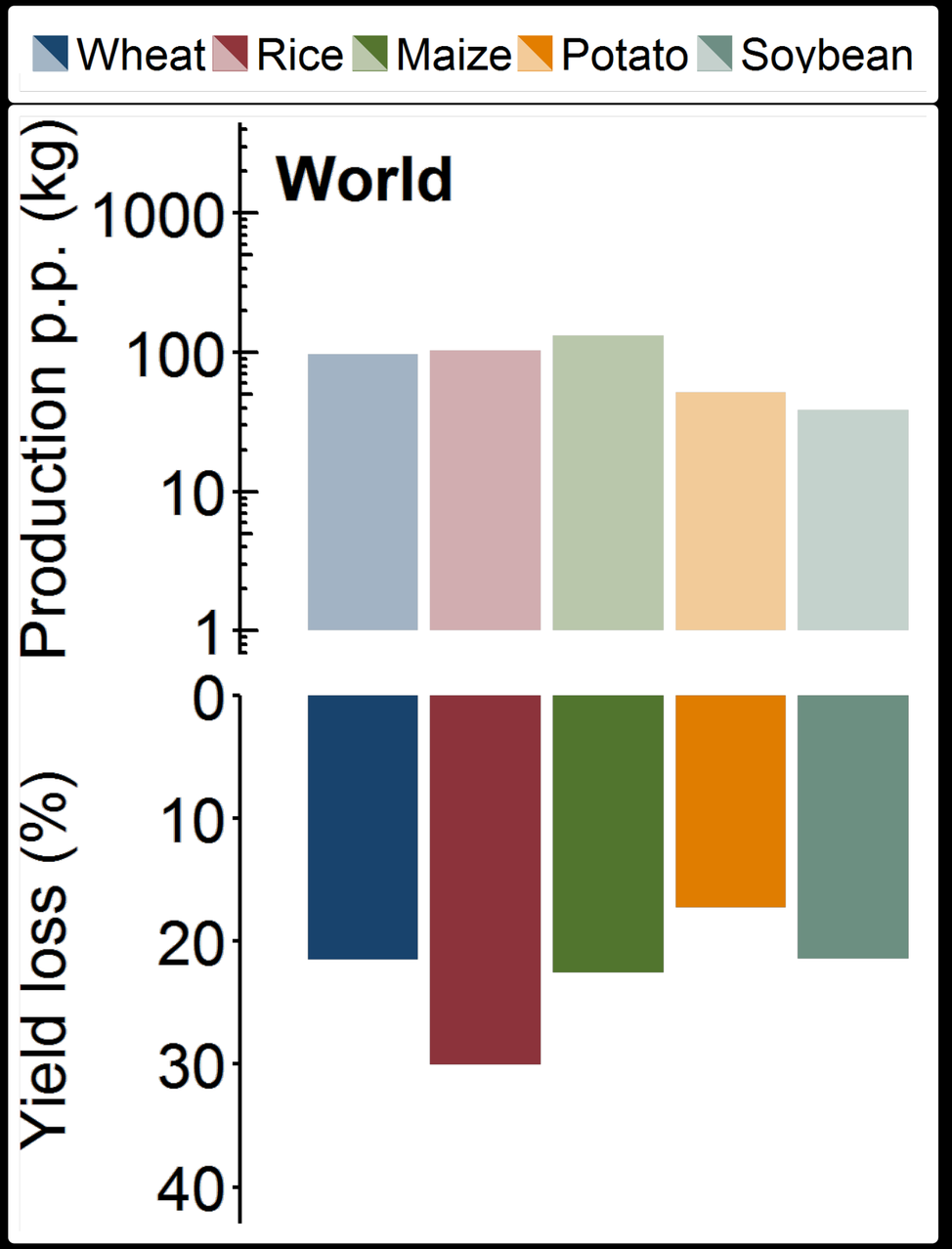
What are the accumulated losses per crop?

- The sum of individual crop losses was computed for each crop globally
- Because interactions in the yield-reducing effects of P&Ps in general lead to less-than-additive effects of yield-reducing factors, this sum is expected to be larger than crop losses from combined P&Ps
- Current empirical and theoretical knowledge are not sufficient to generate estimates that would account for these interactions within the context of the responses in the survey
- Thus our figures in the next section are probably over-estimates

Estimates of crop losses – globally

Losses (%)	Wheat	Rice	Maize	Potato	Soybean
World	21.5	30.0	22.5	17.2	21.4

- Top half of graph shows production per person (kg) *Log scale!*
- Bottom half of graph shows the estimated yield loss per crop (%)

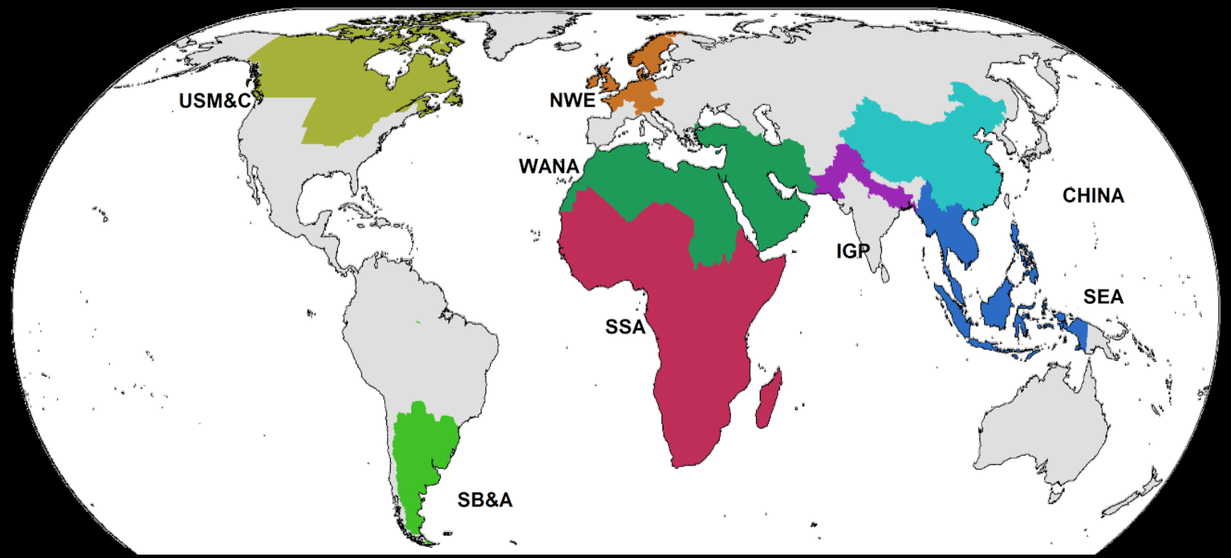


FAOSTAT. Food and Agriculture Organization of the United Nations. FAOSTAT Statistics Database. (2017)
UN Department of Economic and Social Affairs, Population Division. World Urbanization Prospects (2018)

Estimates of crop losses – by food security hotspot

We used the same eight hotspots

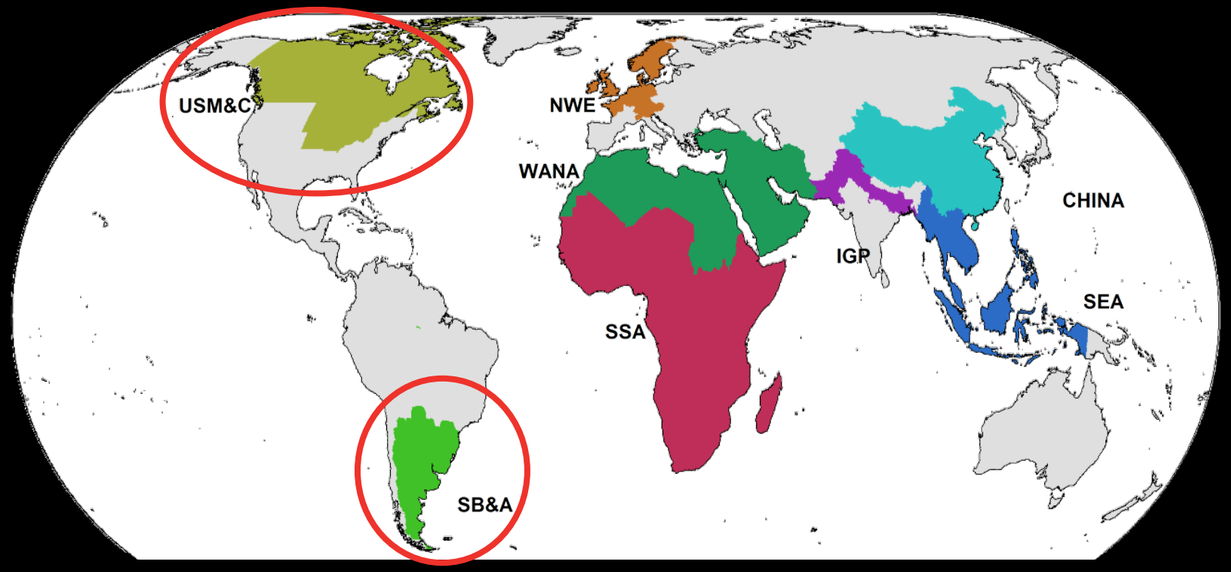
We looked at crop losses (%) and crop production per person (kg) in each one.

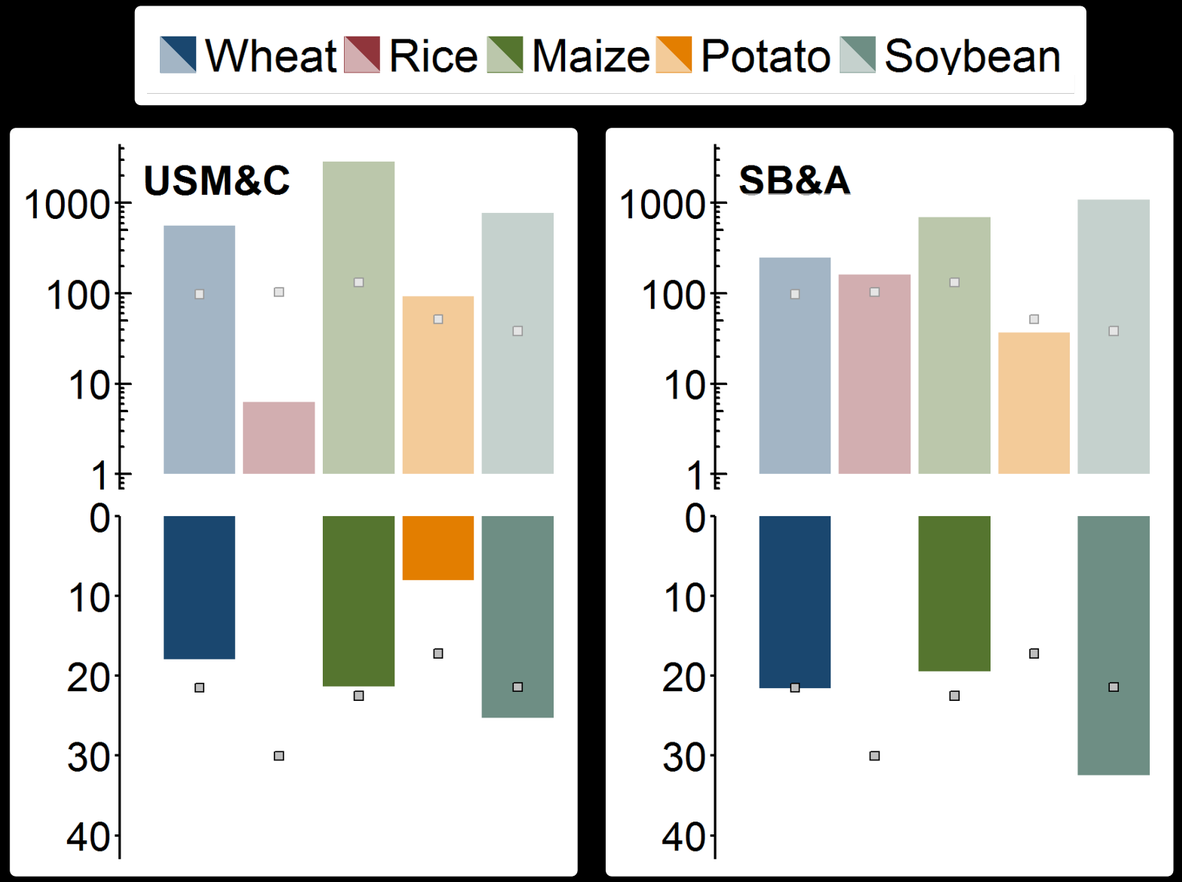


USM&C=US Midwest and Canada; **SB&A**=South Brazil, Paraguay, Uruguay and Argentina; **NWE**=Northwest Europe; **WANA**=West Asia and North Africa; **CHINA**=Mainland China; **SEA**=Southeast Asia; **SSA**=Sub-Saharan Africa; **IGP**=Indo-Gangetic Plains

Estimates of crop losses – USM&C and SB&A

Losses (%)	Wheat	Rice	Maize	Potato	Soybean
World	21.5	30.0	22.5	17.2	21.4
USM&C	17.9		21.3	8.1	25.3
SB&A	21.5		19.5		32.4
NWE					
WANA					
CHINA					
SEA					
SSA					
IGP					





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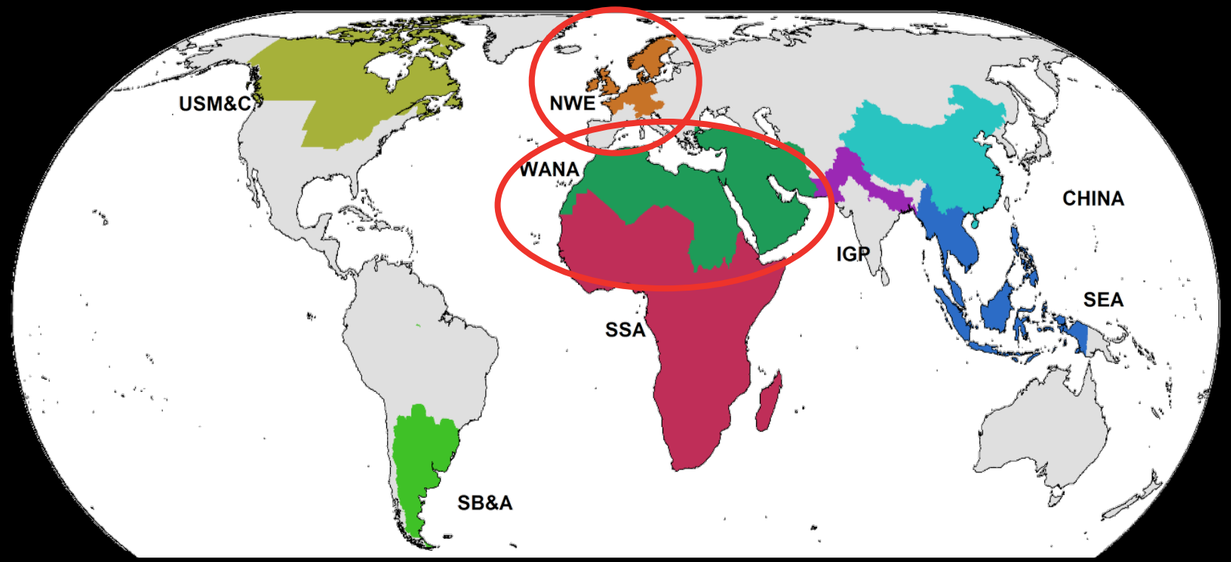
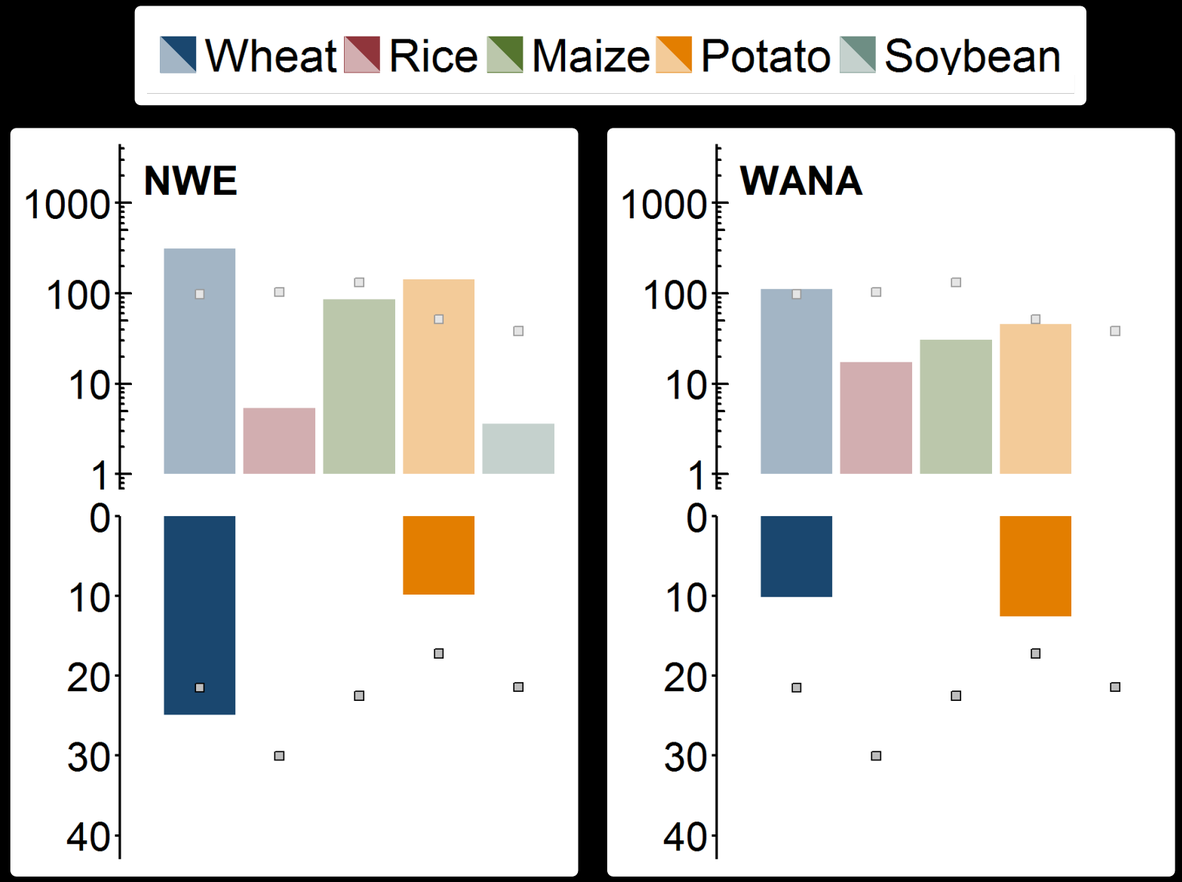
Estimates of crop losses – NWE and WANA

Losses (%)	Wheat	Rice	Maize	Potato	Soybean
World	21.5	30.0	22.5	17.2	21.4
USM&C	17.9		21.3	8.1	25.3
SB&A	21.5		19.5		32.4
NWE	24.9			9.8	
WANA	10.1			12.6	
CHINA					
SEA					
SSA					
IGP					

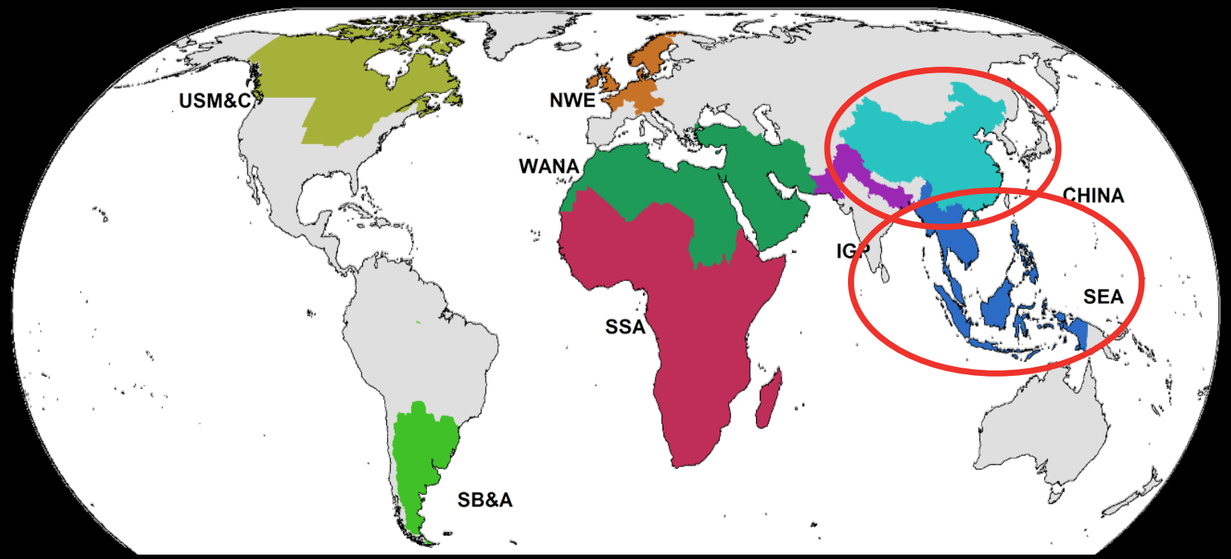


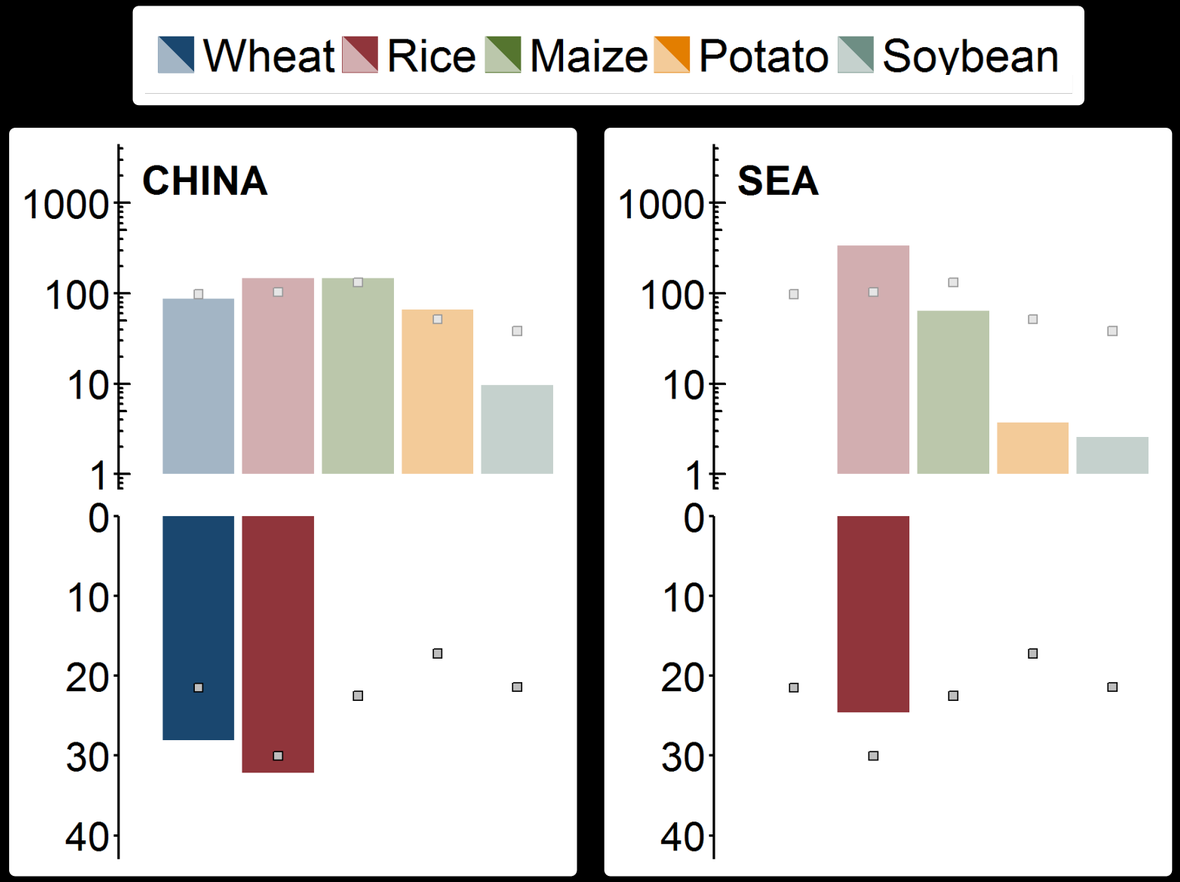


USM&C=US Midwest and Canada; **SB&A**=South Brazil, Paraguay, Uruguay and Argentina; **NWE**=Northwest Europe; **WANA**=West Asia and North Africa; **CHINA**=Mainland China; **SEA**=Southeast Asia; **SSA**=Sub-Saharan Africa; **IGP**=Indo-Gangetic Plains

Estimates of crop losses – CHINA and SEA

Losses (%)	Wheat	Rice	Maize	Potato	Soybean
World	21.5	30.0	22.5	17.2	21.4
USM&C	17.9		21.3	8.1	25.3
SB&A	21.5		19.5		32.4
NWE	24.9			9.8	
WANA	10.1			12.6	
CHINA	28.1	32.2			
SEA		24.6			
SSA					
IGP					





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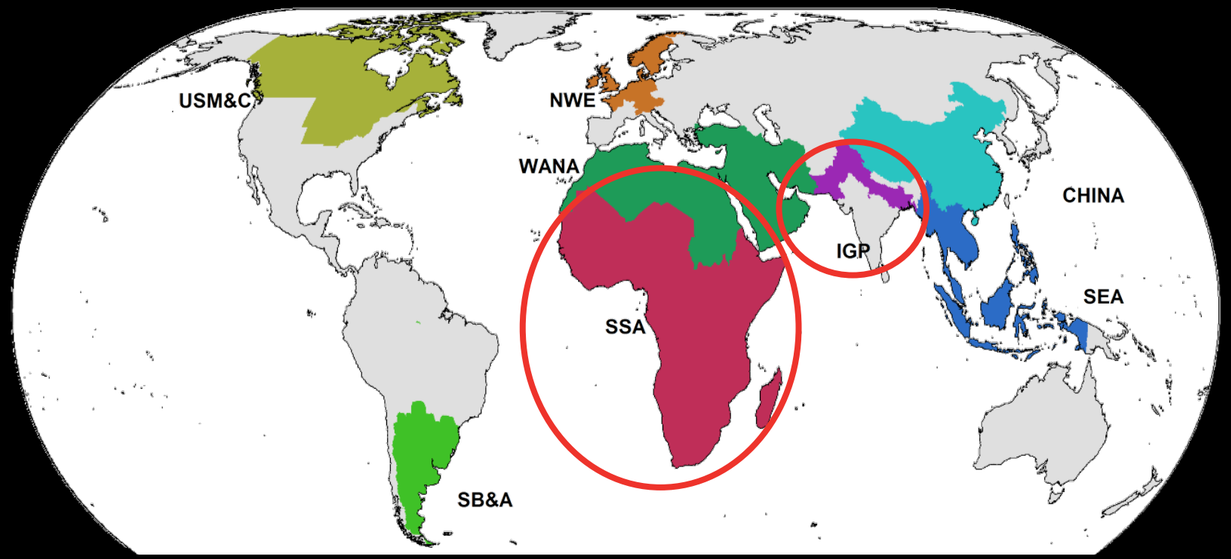
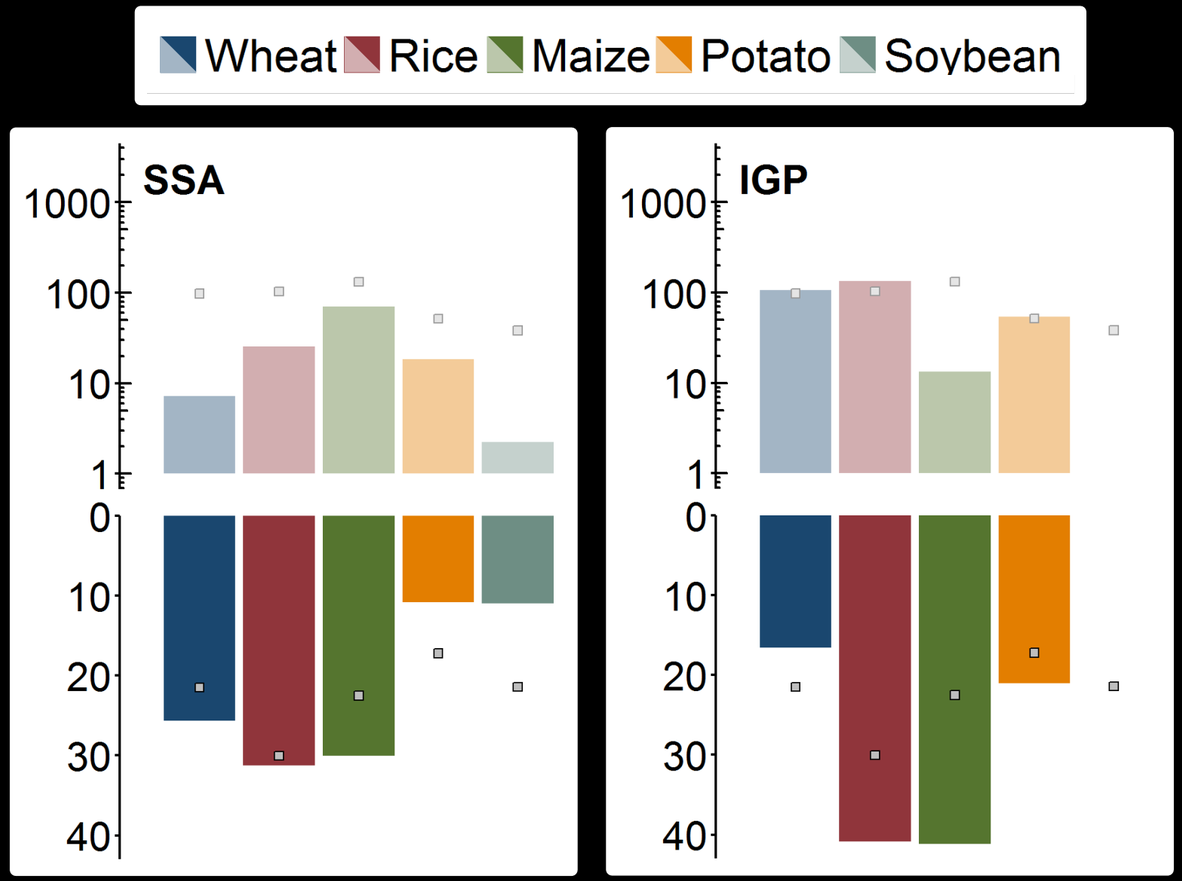
Estimates of crop losses – SSA and IGP

Losses (%)	Wheat	Rice	Maize	Potato	Soybean
World	21.5	30.0	22.5	17.2	21.4
USM&C	17.9		21.3	8.1	25.3
SB&A	21.5		19.5		32.4
NWE	24.9			9.8	
WANA	10.1			12.6	
CHINA	28.1	32.2			
SEA		24.6			
SSA	25.7	31.3	30.1	10.8	11.0
IGP	16.6	40.9	41.1	21.0	





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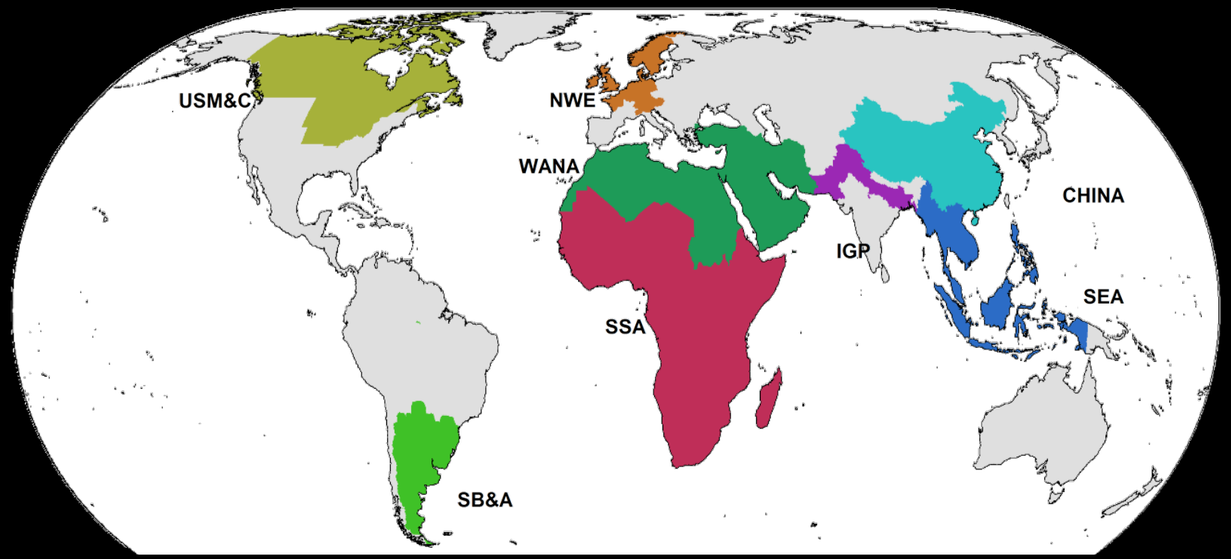
Estimates of crop losses – by food security hotspot

Losses (%)	Wheat	Rice	Maize	Potato	Soybean
World	21.5	30.0	22.5	17.2	21.4
USM&C	17.9		21.3	8.1	25.3
SB&A	21.5		19.5		32.4
NWE	24.9			9.8	
WANA	10.1			12.6	
CHINA	28.1	32.2			
SEA		24.6			
SSA	25.7	31.3	30.1	10.8	11.0
IGP	16.6	40.9	41.1	21.0	

- Very large differences in levels of crop losses among food security hotspots
- Crop losses can be comparatively lower in hotspots that generate large production and surpluses (e.g., USM&C, SB&A), whereas crop losses can be very high in food-insecure hotspots (e.g., SSA, IGP)



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Key messages

We have a snapshot of the quantitative losses associated with many individual P&Ps on five key food crops in the world

The assessment appears to be internally consistent; good comparisons against pest, crop and region specific studies; our global loss estimates are in the same range as previous studies

The results allow ranking the impacts of P&Ps globally as well as regionally, thus incorporating large differences in agroecosystems and production situations

There are variations in crop health patterns & associated losses across food security hotspots. This suggests successive levels of efficiency in crop health management across hotspots and variable scope for improvement

Towards a global surveillance system for crop health

Pexels

The role of expert knowledge to assess the impacts of P&P

Expert surveys can provide a basis for research and policy prioritisation alth management, by considering the impact of chronic and emerging P&Ps.

Validation remains a challenge as foes access to field and experimental data in food security hotspots.

Expert assessments can go beyond surveys, e.g. to assess current and future trends in crop health in key crop(plant) x ecoregion combinations.

2 More coordinated action for crop protection

2020 will be the International Year of Plant Health (IYPH)

It aims to trigger greater global collaboration to support plant health policies at all levels, and to contribute to the Sustainable Development Agenda

Coordinated action across Plant Protection Organisations, research institutions, universities and private companies is needed to globally harmonize appropriate best practices to detect, communicate and respond to crop diseases across all scales of production

Pathogens and pests are not limited by geographic borders. Crop protection strategies must reflect our interconnected world

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We wish to thank Greg Johnson, President of the ISPP, and Daniel Hüberli, ISPP Newsletter Editor, for the instrumental and friendly support they have given to this project all along. We thank the 219 Global Crop Health Survey respondents in 67 countries.

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- **http://globalcrophealth.org/**

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