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Agricultural Innovation—The United States and the Developing World

Philip G. Pardey

University of Minnesota

USDA 92nd Outlook Forum, Transforming Agriculture

Session: Applying USDA Technological Achievements to Global Agricultural Challenges

February 26, 2016 Marriott Hotel, Arlington

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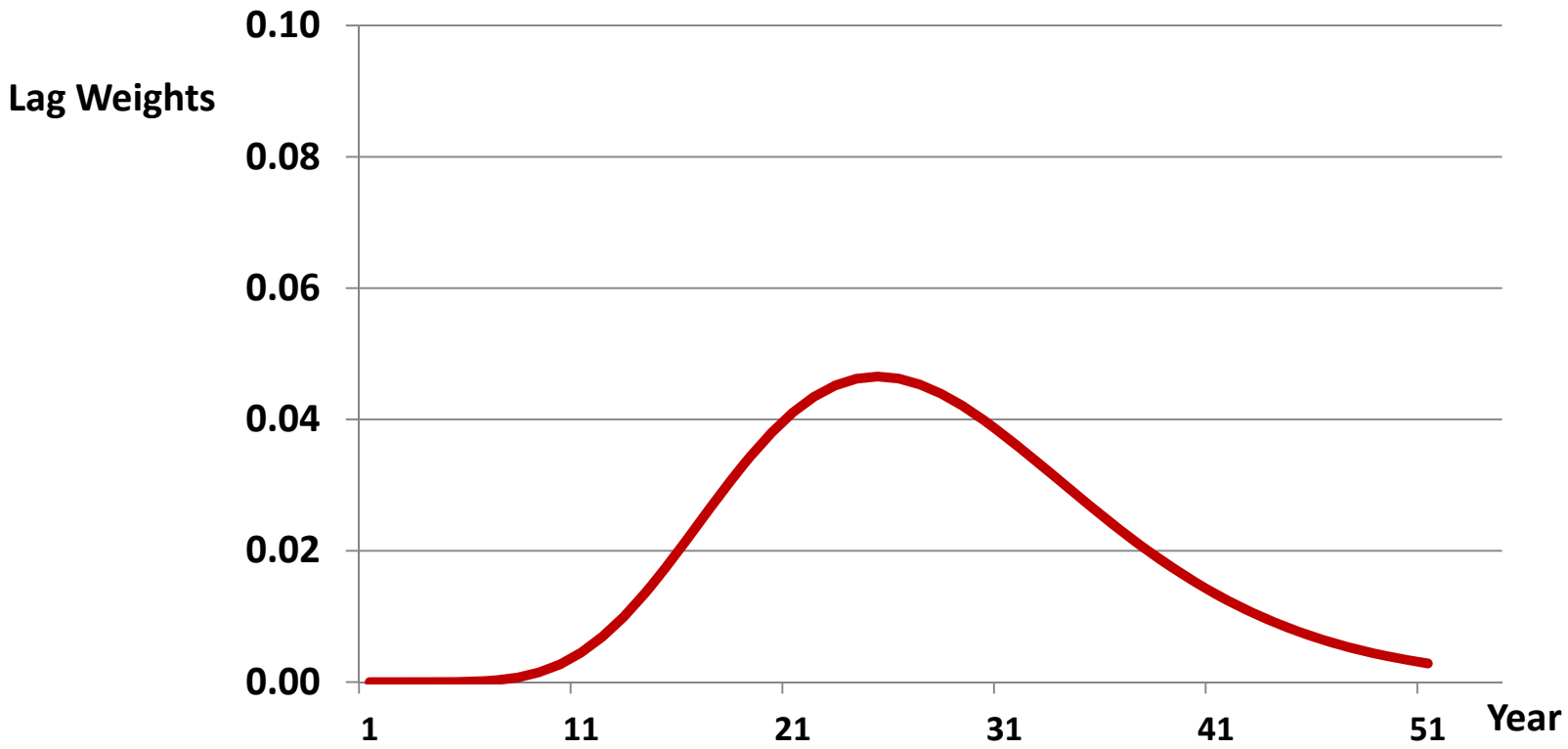
Outline

- Persistence Pays! – R&D and Adoption Lags
- Changing Food and Agricultural R&D Realities Worldwide
- U.S. Agricultural Innovations in a Global Context
  - The Case of Wheat Rusts

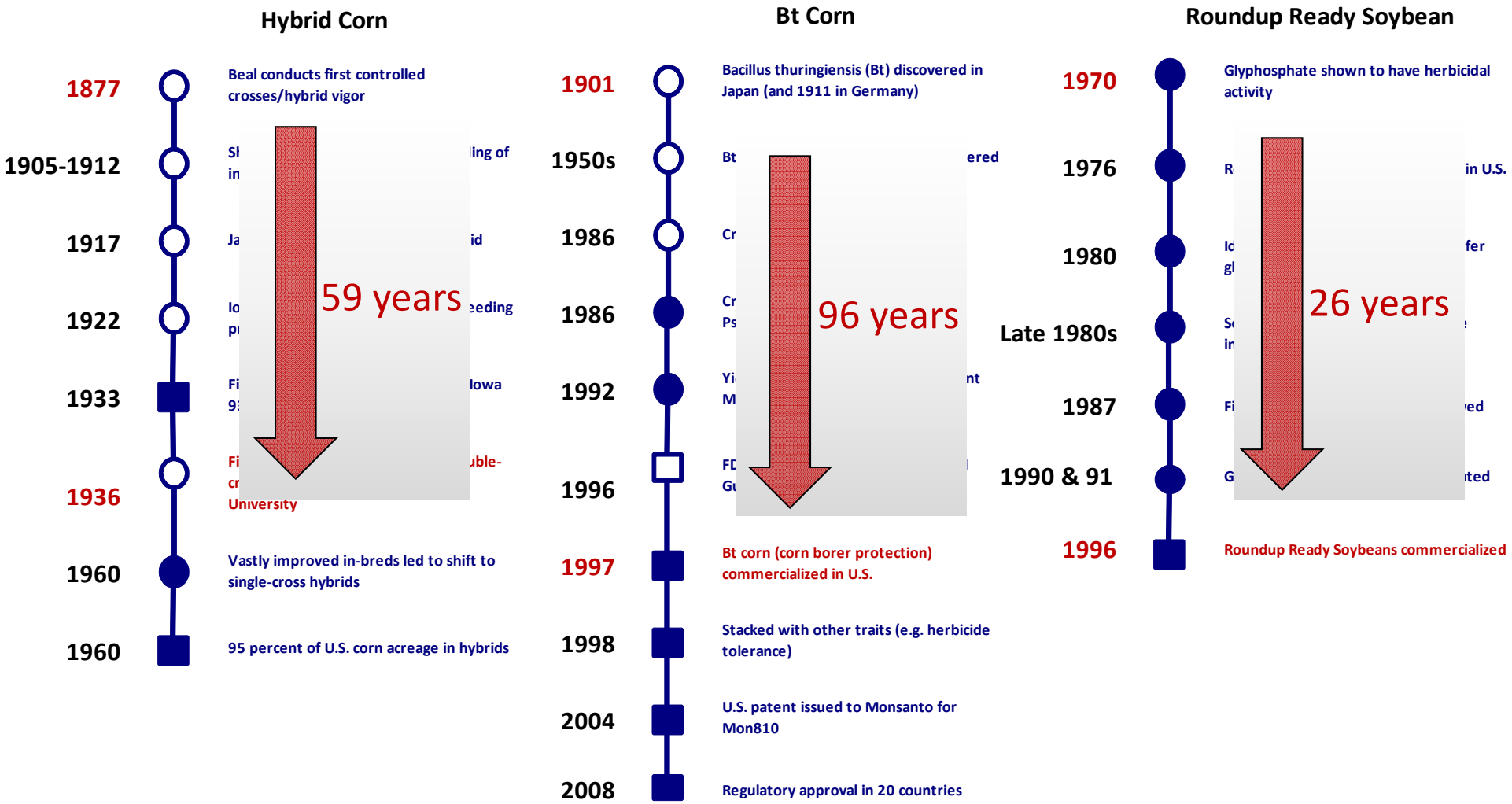
From Innovation Investment to Adoption and Impact

R&D Investments → **Farm Productivity Growth**



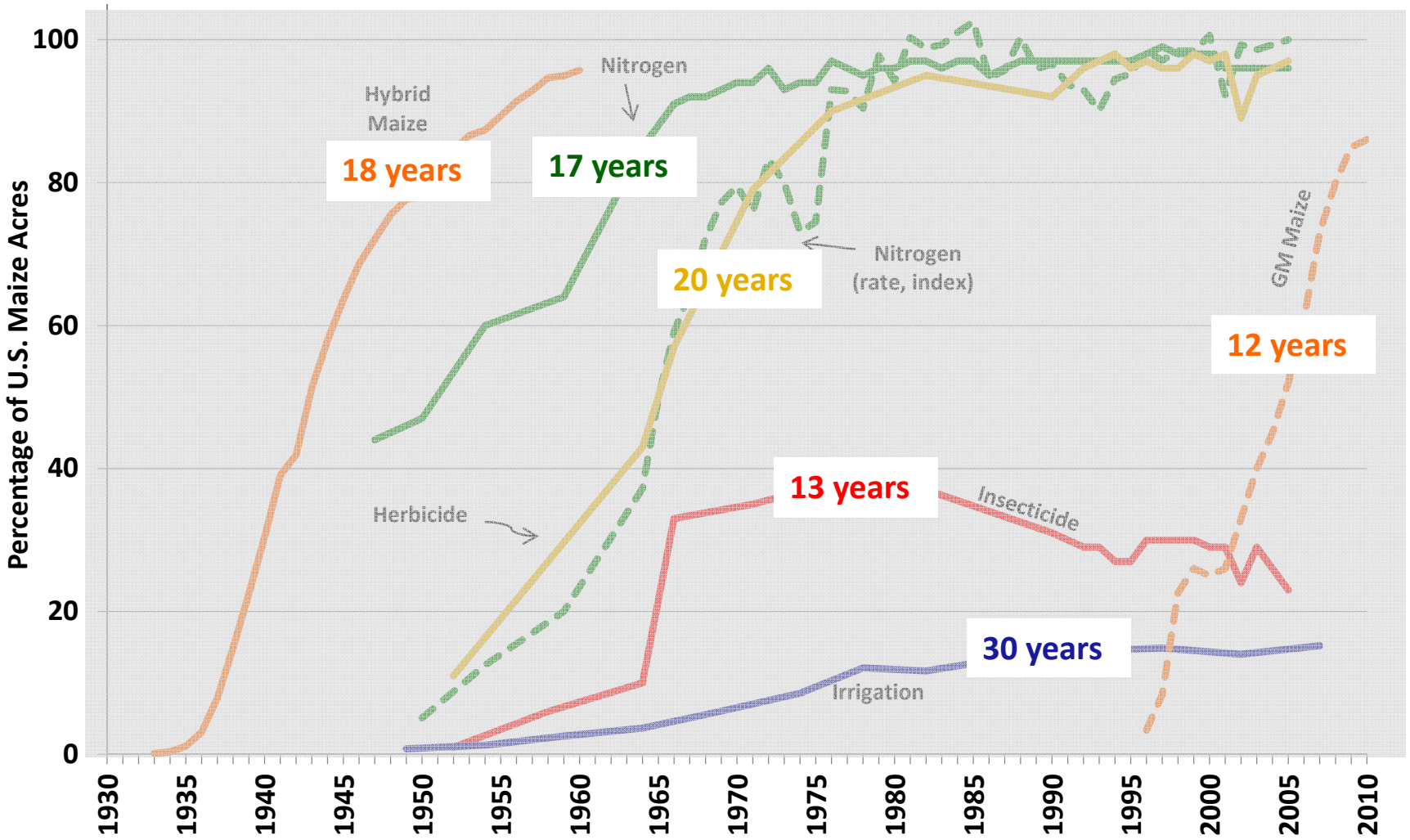
Source: Alston, Anderson, James and Pardey (2010, 2011)

Illustrative Technology Timelines (US)



Source: Pardey , Alston and Ruttan (2008) and Alston et al. (2010)

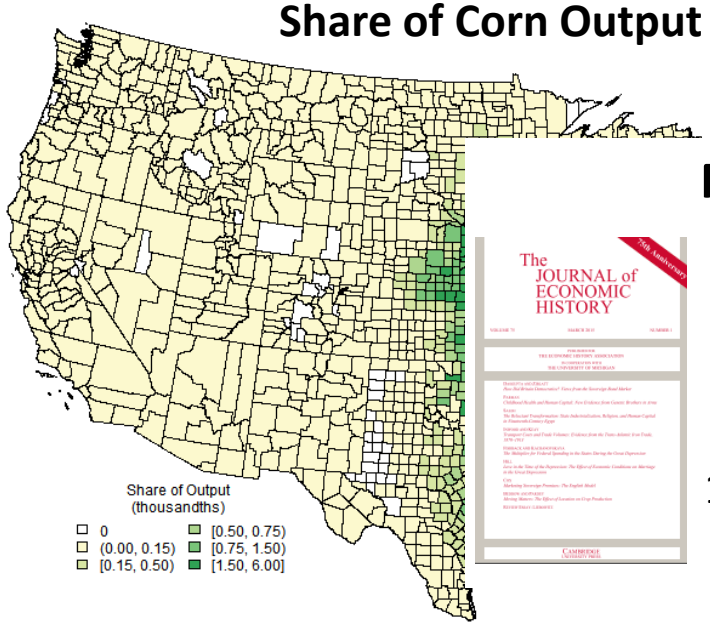
U.S. Maize Technology Adoption Lags



Source: Beddow (2012)

Corn Movement in the U.S., 1899-2007

Share of Corn Output by County, 1899



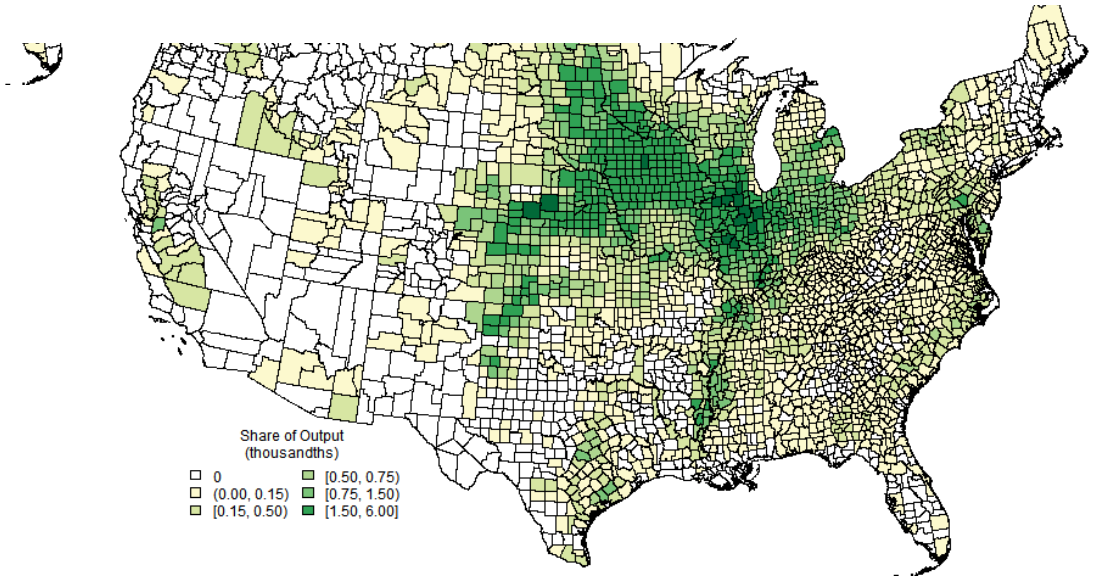
Moving Matters

279 kilometers north

342 kilometers west

16 to 21 percent of corn output growth

ut by County, 2007

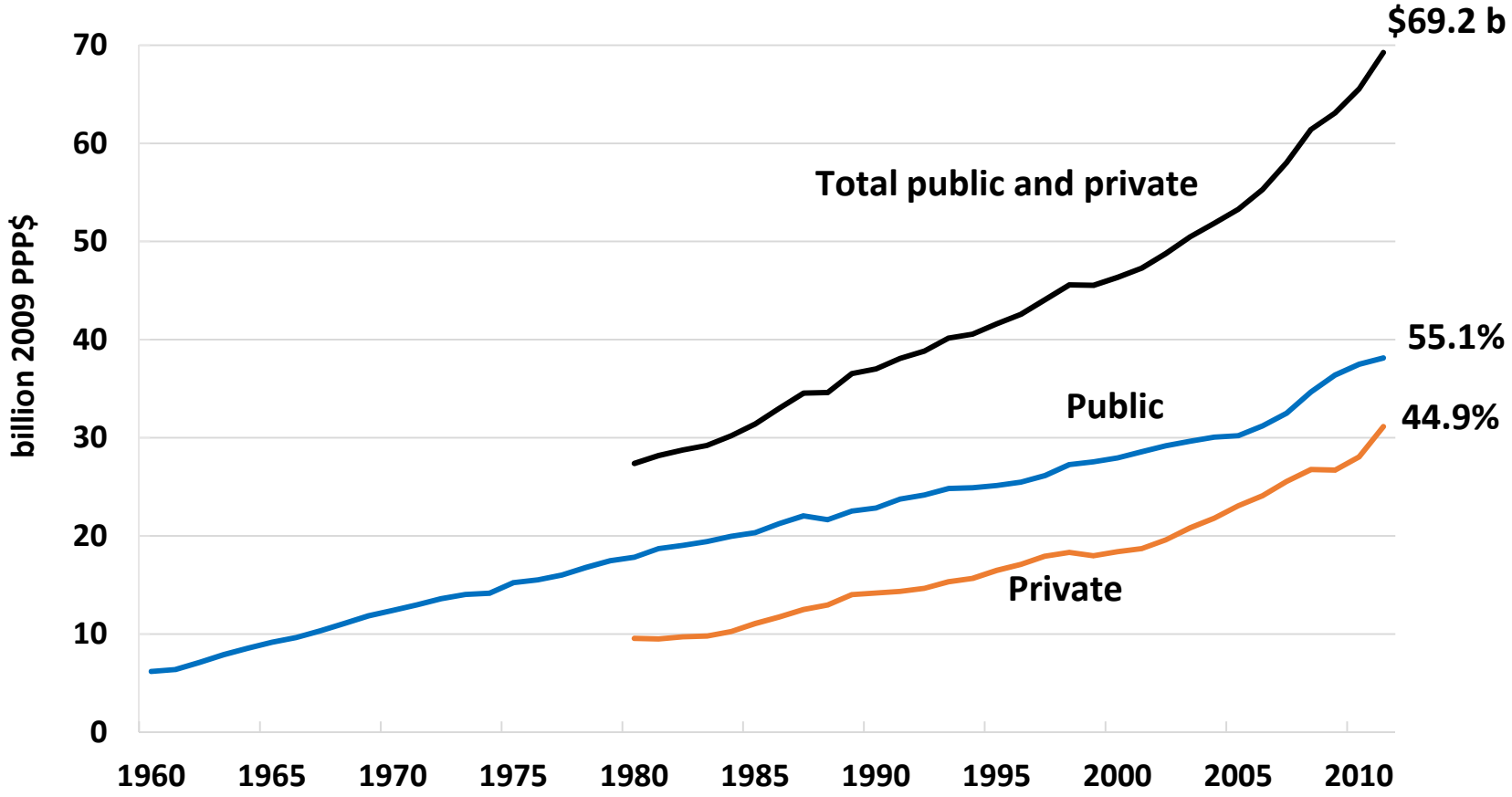


Source: Beddow and Pardey (2015)

Shifting Ground

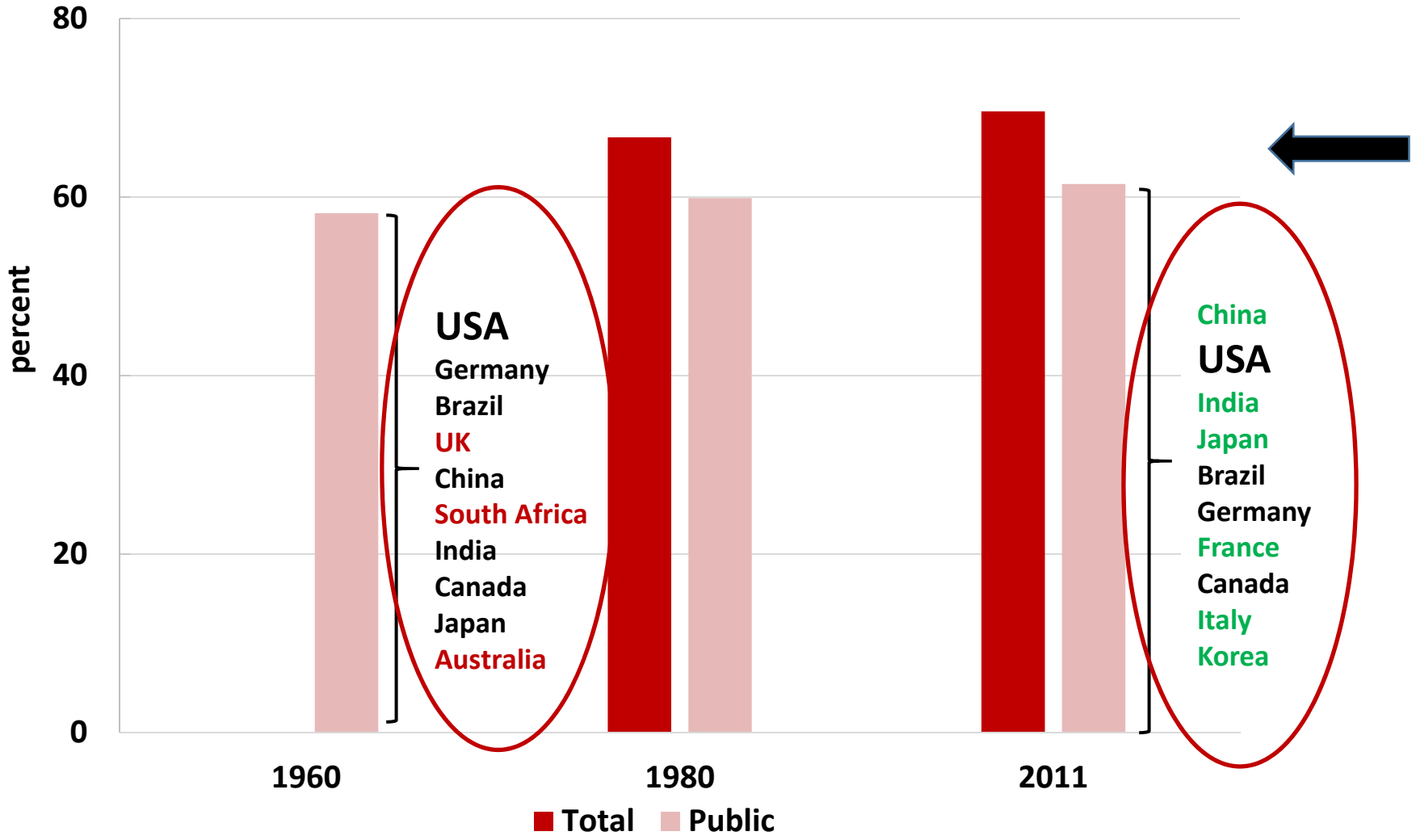
The Global Food and Agricultural R&D Landscape

Global Public and Private Food & Agricultural R&D, 1960-2011

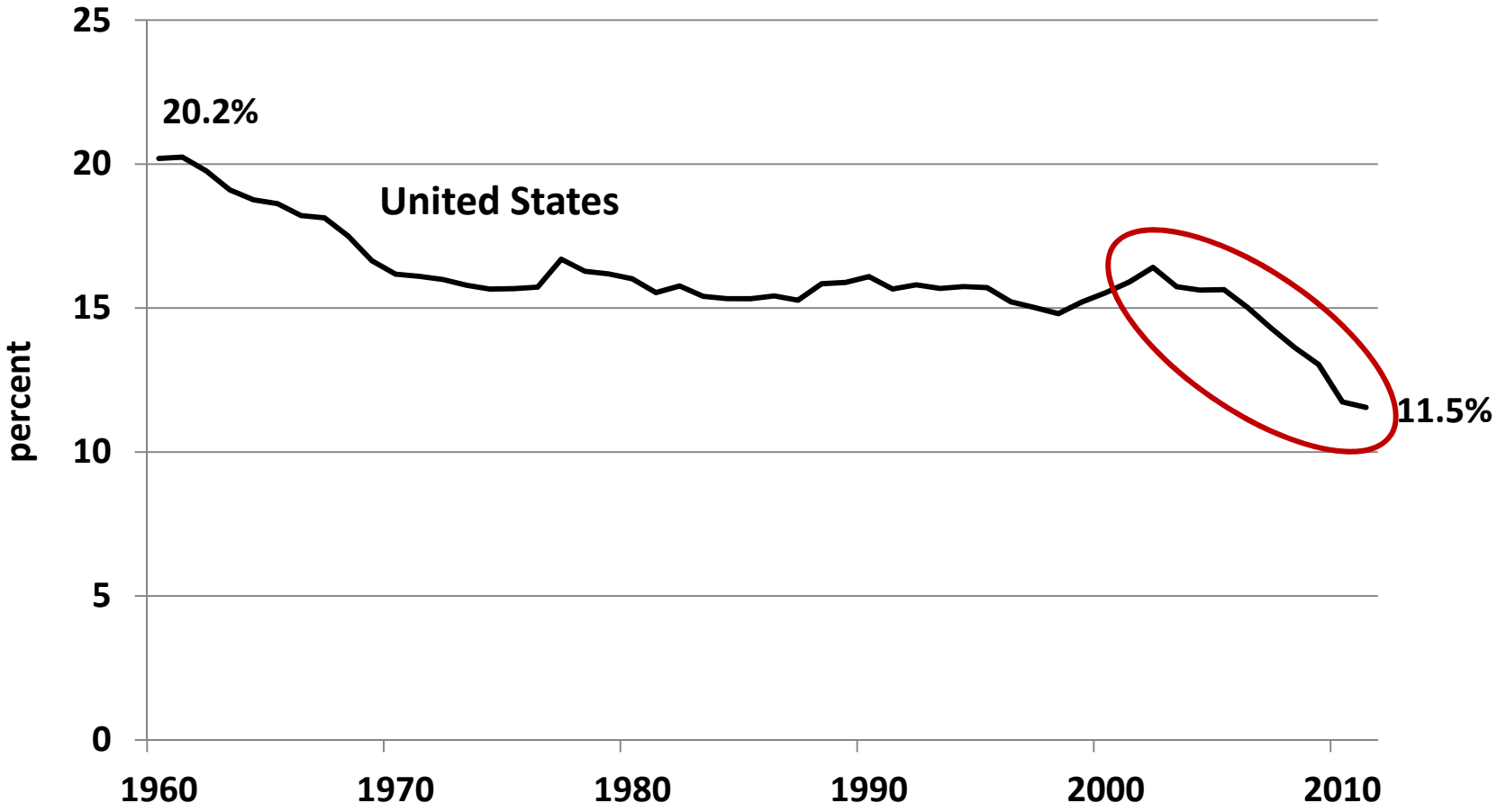


Source: Pardey, Chan-Kang, Beddow and Dehmer (2016, in process)

Spatial Concentration -- Top 10 Country Share and Rank

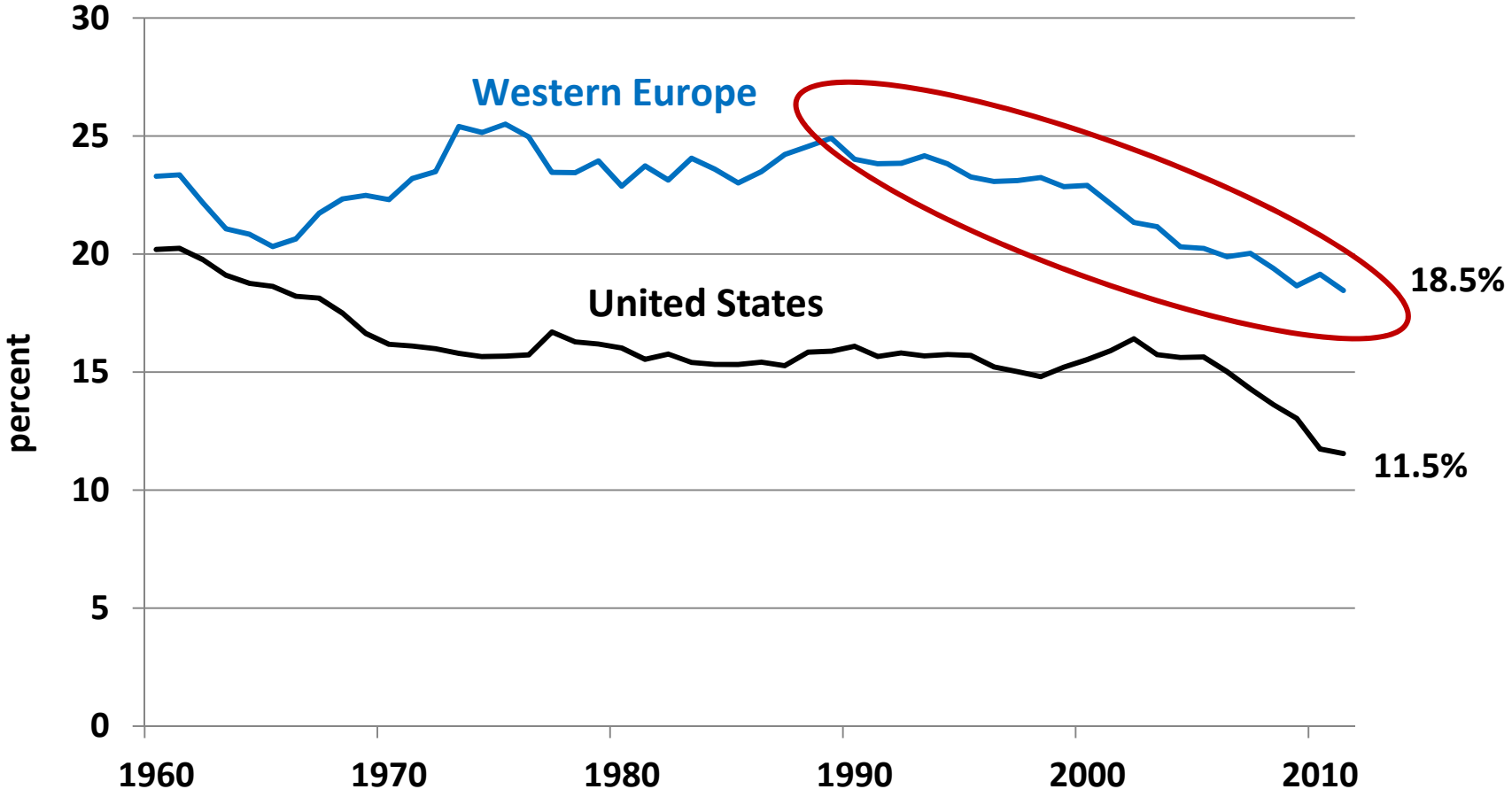


Shifting Global Shares of Public Food & Ag R&D, 1960-2011



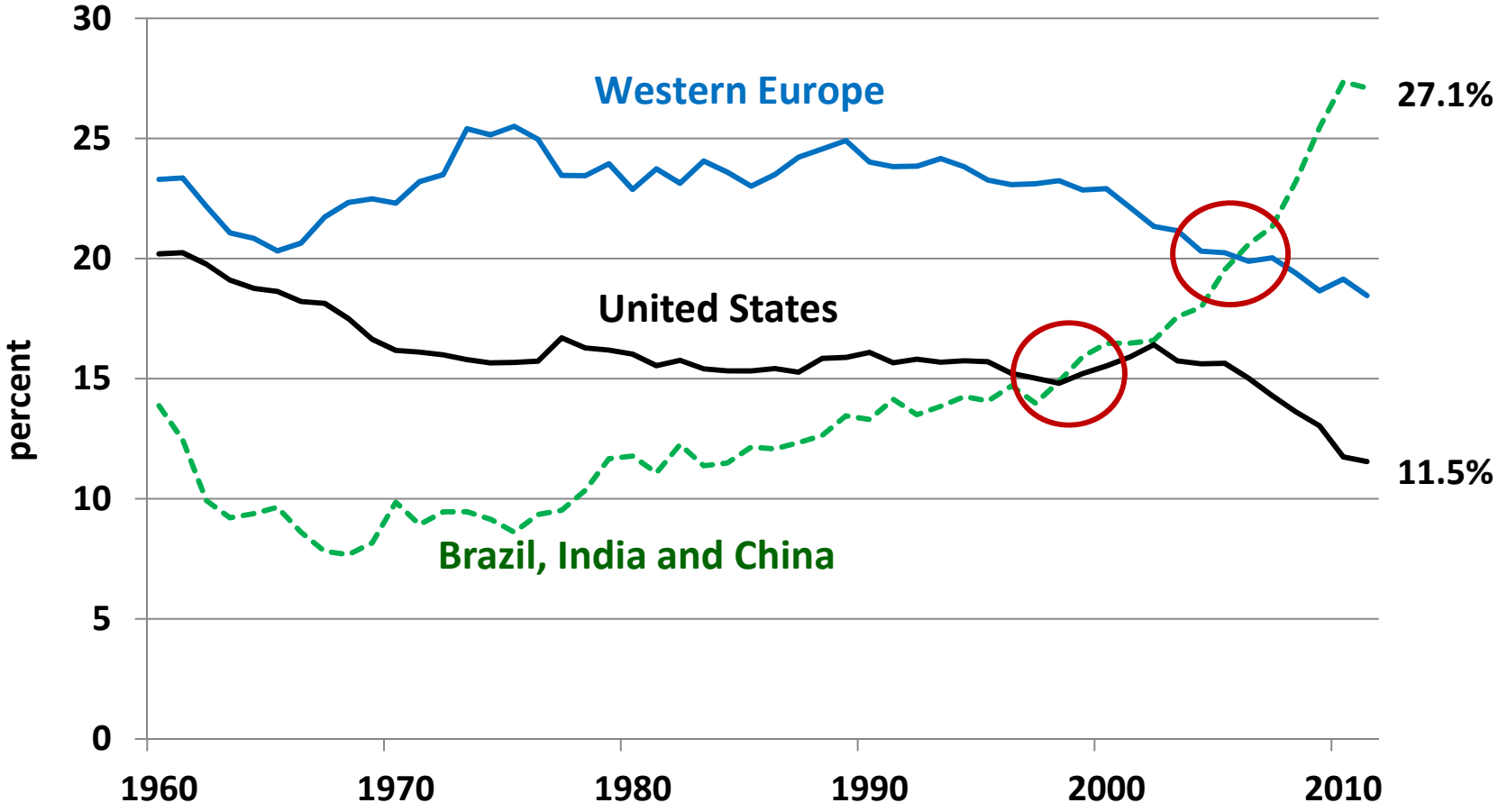
Source: Pardey, Chan-Kang, Beddow and Dehmer (2016, in process)

Shifting Global Shares of Public Food & Ag R&D, 1960-2011



Source: Pardey, Chan-Kang, Beddow and Dehmer (2016, in process)

Shifting Global Shares of Public Food & Ag R&D, 1960-2011



Source: Pardey, Chan-Kang, Beddow and Dehmer (2016, in process)

Agricultural R&D, Innovation and Adoption

Sustainable Productivity Performance

- Economic challenges
  - Comparative advantage and international competiveness

- Environmental challenges and changes
  - Climate (drought, heat stress, water logging etc)
  - Crop pest and diseases

Productivity Maintenance – The Case of Wheat Rusts

Running hard to stand still!

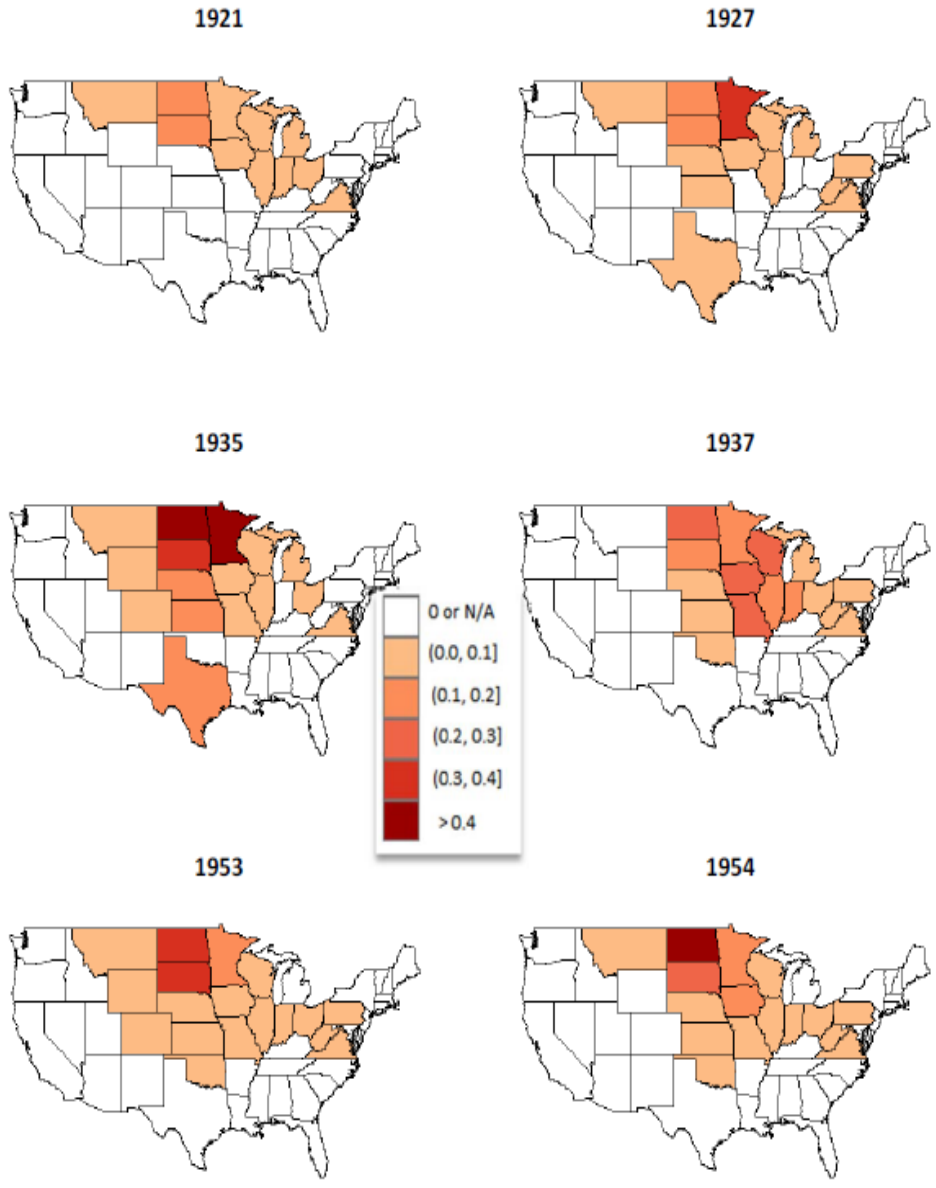
Stem Rust

Stripe Rust

Leaf Rust

Stem Rust

Appendix Figure 1: Reported State Losses (share) Due to Stem Rust in the U.S., Selected Years.

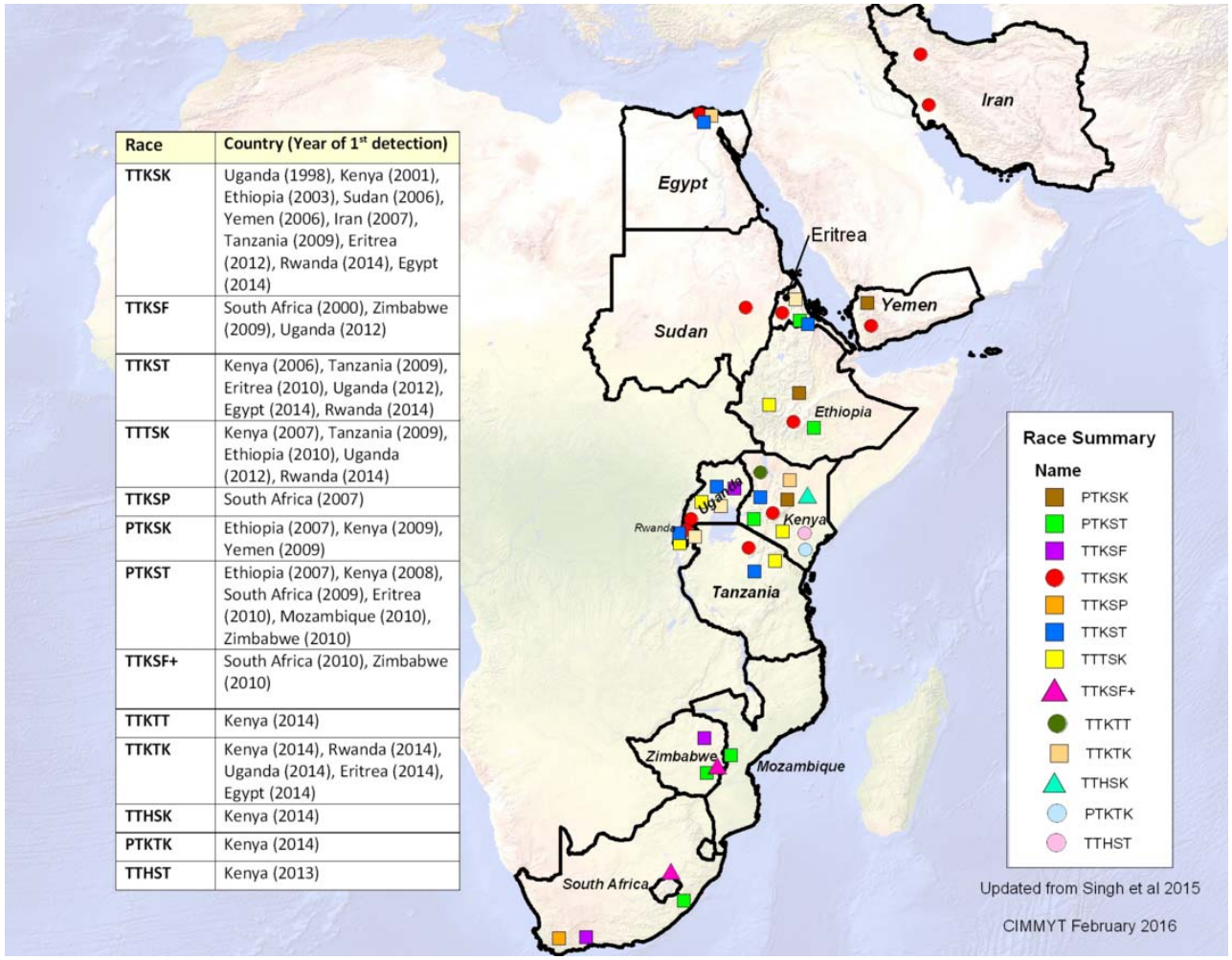


Source: Created by the authors using data from USDA, ARS (2011).

The Spread of Ug99 Stem Rust

Now 13 known variants spread across 13 countries

Race	Country (Year of 1st detection)
TTKSK	Uganda (1998), Kenya (2001), Ethiopia (2003), Sudan (2006), Yemen (2006), Iran (2007), Tanzania (2009), Eritrea (2012), Rwanda (2014), Egypt (2014)
TTKSF	South Africa (2000), Zimbabwe (2009), Uganda (2012)
TTKST	Kenya (2006), Tanzania (2009), Eritrea (2010), Uganda (2012), Egypt (2014), Rwanda (2014)
TTTSK	Kenya (2007), Tanzania (2009), Ethiopia (2010), Uganda (2012), Rwanda (2014)
TTKSP	South Africa (2007)
PTKSK	Ethiopia (2007), Kenya (2009), Yemen (2009)
PTKST	Ethiopia (2007), Kenya (2008), South Africa (2009), Eritrea (2010), Mozambique (2010), Zimbabwe (2010)
TTKSF+	South Africa (2010), Zimbabwe (2010)
TTKTT	Kenya (2014)
TTKTK	Kenya (2014), Rwanda (2014), Uganda (2014), Eritrea (2014), Egypt (2014)
TTHSK	Kenya (2014)
PTKTK	Kenya (2014)
TTHST	Kenya (2013)



Cereal Disease Laboratory

- Research Projects
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The Cereal Rusts

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Cereal Rust Fungi: Genetics, Population Biology, and Host-Pathogen Interactions

Fusarium Head Blight of Cereals: Pathogen Biology and Host Resistance

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CEREAL DISEASE LABORATORY
1551 Lindig Avenue
St. Paul MN 55108

Mission:
The mission of the Cereal Disease Laboratory is to reduce losses in wheat, oat, and barley to major diseases including leaf rust, stem rust, and Fusarium head blight. This mission is accomplished through research on the biology of the pathogens that cause these diseases and on methods to enhance disease resistance in small grains. Program objectives are to: (1) identify genes used by plants in defense against pathogens and determine their cellular and biochemical mechanisms of action; (2) elucidate molecular

Barberry
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Ug99 - emerging virulent races

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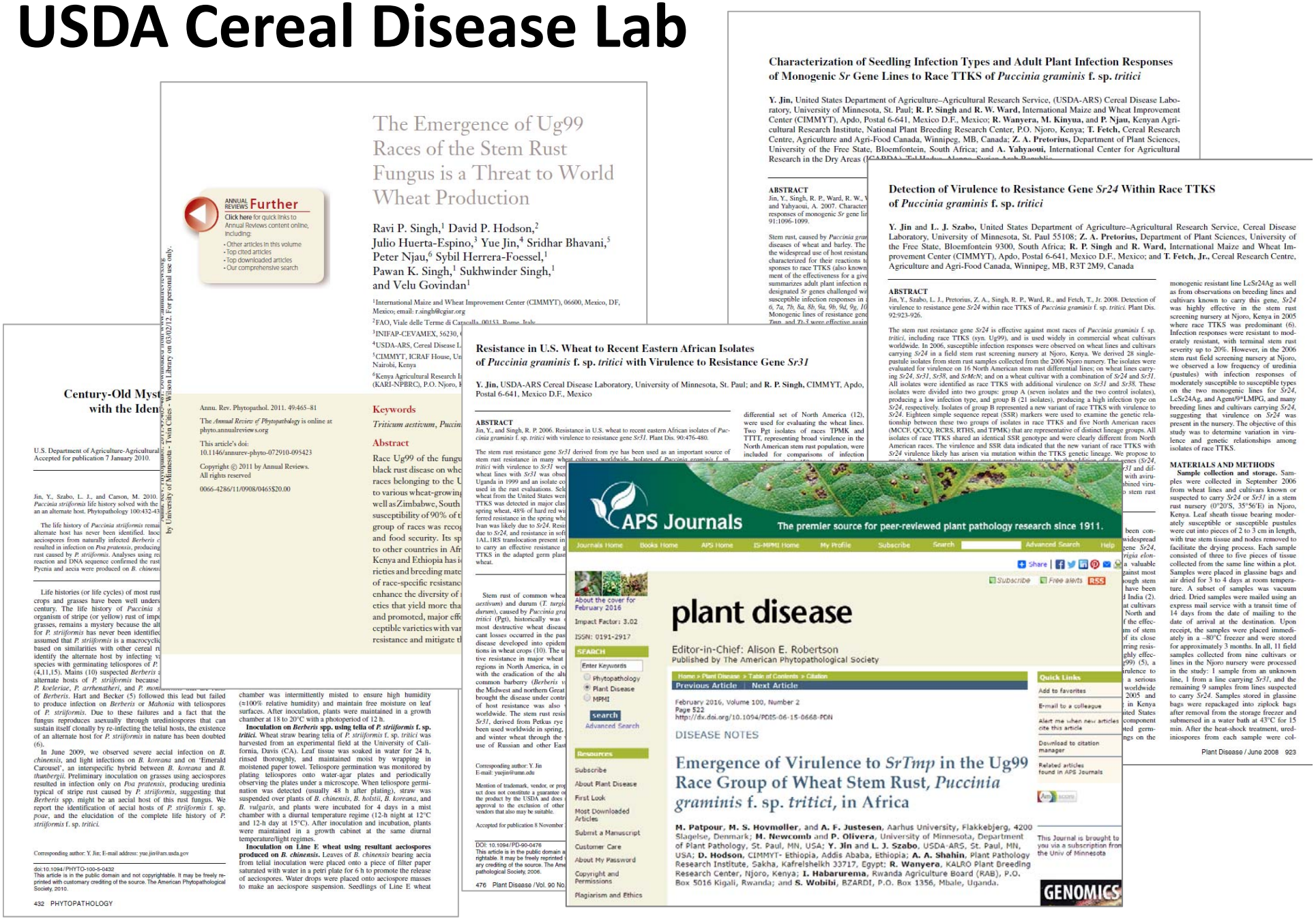
USDA Cereal Disease Lab



Characterization of Seedling Infection Types and Adult Plant Infection Responses of Monogenic *Sr* Gene Lines to Race TTKS of *Puccinia graminis* f. sp. *tritici*

Y. Jin, United States Department of Agriculture–Agricultural Research Service, (USDA-ARS) Cereal Disease Laboratory, University of Minnesota, St. Paul; R. P. Singh and R. W. Ward, International Maize and Wheat Improvement Center (CIMMYT), Apdo, Postal 6-641, Mexico D.F., Mexico; R. Wanyera, M. Kinyua, and P. Njau, Kenyan Agricultural Research Institute, National Plant Breeding Research Center, P.O. Njoro, Kenya; T. Fetch, Cereal Research Centre, Agriculture and Agri-Food Canada, Winnipeg, MB, Canada; Z. A. Pretorius, Department of Plant Sciences, University of the Free State, Bloemfontein, South Africa; and A. Yahyaoui, International Center for Agricultural Research in the Dry Areas (ICARDA), Tel Hadya, Aleppo, Syrian Arab Republic

ABSTRACT

Jin, Y., Singh, R. P., Ward, R. W., and Yahyaoui, A. 2007. Character responses of monogenic *Sr* gene lin 91:1096-1099.

Stem rust, caused by *Puccinia gra* diseases of wheat and barley. The the widespread use of host resistan characterized for their reactions t sponses to race TTKS (also known ment of the effectiveness for a giv summarizes adult plant infection r designated *Sr* genes challenged wi susceptible infection responses in *6, 7a, 7b, 8a, 8b, 9a, 9b, 9d, 9g, 10* Monogenic lines of resistance gene *Tmp*, and *Tt-3* were effective again

Detection of Virulence to Resistance Gene *Sr24* Within Race TTKS of *Puccinia graminis* f. sp. *tritici*

Y. Jin and L. J. Szabo, United States Department of Agriculture–Agricultural Research Service, Cereal Disease Laboratory, University of Minnesota, St. Paul 55108; Z. A. Pretorius, Department of Plant Sciences, University of the Free State, Bloemfontein 9300, South Africa; R. P. Singh and R. Ward, International Maize and Wheat Improvement Center (CIMMYT), Apdo, Postal 6-641, Mexico D.F., Mexico; and T. Fetch, Jr., Cereal Research Centre, Agriculture and Agri-Food Canada, Winnipeg, MB, R3T 2M9, Canada

ABSTRACT

Jin, Y., Szabo, L. J., Pretorius, Z. A., Singh, R. P., Ward, R., and Fetch, T., Jr. 2008. Detection of virulence to resistance gene *Sr24* within race TTKS of *Puccinia graminis* f. sp. *tritici*. Plant Dis. 92:923-926.

The stem rust resistance gene *Sr24* is effective against most races of *Puccinia graminis* f. sp. *tritici*, including race TTKS (syn. Ug99), and is used widely in commercial wheat cultivars worldwide. In 2006, susceptible infection responses were observed on wheat lines and cultivars carrying *Sr24* in a field stem rust screening nursery at Njoro, Kenya. We derived 28 single-pustule isolates from stem rust samples collected from the 2006 Njoro nursery. The isolates were evaluated for virulence on 16 North American stem rust differential lines; on wheat lines carrying *Sr24*, *Sr31*, *Sr38*, and *SrMcN*; and on a wheat cultivar with a combination of *Sr24* and *Sr31*. All isolates were identified as race TTKS with additional virulence on *Sr31* and *Sr38*. These isolates were divided into two groups: group A (seven isolates and the two control isolates), producing a low infection type, and group B (21 isolates), producing a high infection type on *Sr24*, respectively. Isolates of group B represented a new variant of race TTKS with virulence to *Sr24*. Eighteen simple sequence repeat (SSR) markers were used to examine the genetic relationship between these two groups of isolates in race TTKS and five North American races (MCCF, QCCQ, RCRS, RTHS, and TPMK) that are representative of distinct lineage groups. All isolates of race TTKS shared an identical SSR genotype and were clearly different from North American races. The virulence and SSR data indicated that the new variant of race TTKS with *Sr24* virulence likely has arisen via mutation within the TTKS genetic lineage. We propose to

MATERIALS AND METHODS

Sample collection and storage. Samples were collected in September 2006 from wheat lines and cultivars known or suspected to carry *Sr24* or *Sr31* in a stem rust nursery (0°20'S, 35°56'E) in Njoro, Kenya. Leaf sheath tissue bearing moderately susceptible or susceptible pustules were cut into pieces of 2 to 3 cm in length, with true stem tissue and nodes removed to facilitate the drying process. Each sample consisted of three to five pieces of tissue collected from the same line within a plot. Samples were placed in glassine bags and air dried for 3 to 4 days at room temperature. A subset of samples was vacuum dried. Dried samples were mailed using an express mail service with a transit time of 14 days from the date of mailing to the date of arrival at the destination. Upon receipt, the samples were placed immediately in a −80°C freezer and were stored for approximately 3 months. In all, 11 field samples collected from nine cultivars or lines in the Njoro nursery were processed in the study: 1 sample from an unknown line, 1 from a line carrying *Sr31*, and the remaining 9 samples from lines suspected to carry *Sr24*. Samples stored in glassine bags were repackaged into ziplock bags after removal from the storage freezer and submersed in a water bath at 43°C for 15 min. After the heat-shock treatment, urediniospores from each sample were col-

monogenic resistant line LcSr24Ag as well as from observations on breeding lines and cultivars known to carry this gene, *Sr24* was highly effective in the stem rust screening nursery at Njoro, Kenya in 2005 where race TTKS was predominant (6). Infection responses were resistant to moderately resistant, with terminal stem rust severity up to 20%. However, in the 2006 stem rust field screening nursery at Njoro, we observed a low frequency of uredinia (pustules) with infection responses of moderately susceptible to susceptible types on the two monogenic lines for *Sr24*, LcSr24Ag, and Agent/9*LMPG, and many breeding lines and cultivars carrying *Sr24*, suggesting that virulence on *Sr24* was present in the nursery. The objective of this study was to determine variation in virulence and genetic relationships among isolates of race TTKS.

Plant Disease / June 2008 923

The Emergence of Ug99 Races of the Stem Rust Fungus is a Threat to World Wheat Production

Ravi P. Singh,[1] David P. Hodson,[2] Julio Huerta-Espino,[3] Yue Jin,[4] Sridhar Bhavani,[5] Peter Njau,[6] Sybil Herrera-Foessel,[1] Pawan K. Singh,[1] Sukhwinder Singh,[1] and Velu Govindan[1]

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[5]CIMMYT, ICRAF House, Un Nairobi, Kenya

[6]Kenya Agricultural Research I (KARI-NPBRC), P.O. Njoro,

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Keywords

Triticum aestivum, *Puccin*

Abstract

Race Ug99 of the fungu black rust disease on whe races belonging to the U to various wheat-growing well as Zimbabwe, South susceptibility of 90% of t group of races was recog and food security. Its sp to other countries in Afr Kenya and Ethiopia has i rieties and breeding mate of race-specific resistanc enhance the diversity of eties that yield more tha and promoted, major effe ceptible varieties with var resistance and mitigate t

Century-Old Myst with the Iden

U.S. Department of Agriculture-Agricultural Accepted for publication 7 January 2010.

Jin, Y., Szabo, L. J., and Carson, M. 2010. *Puccinia striiformis* life history solved with the an alternate host. Phytopathology 100:432-4

The life history of *Puccinia striiformis* remai alternate host has never been identified. Inoc aeciospores from naturally infected *Berberis* resulted in infection on *Poa pratensis*, producing rust caused by *P. striiformis*. Analyses using re reaction and DNA sequence confirmed the rust Pycnia and aecia were produced on *B. chinens*

Life histories (or life cycles) of most rust crops and grasses have been well unders century. The life history of *Puccinia* organism of stripe (or yellow) rust of impo grasses, remains a mystery because the alt for *P. striiformis* has never been identifie assumed that *P. striiformis* is a macrocyclic based on similarities with other cereal r identify the alternate host by infecting v species with germinating teliospores of *P.* (4,11,15). Mains (10) suspected *Berberis* alternate hosts of *P. striiformis* because *P. koeleriae*, *P. arrhenatheri*, and *P. mon* of *Berberis*. Hart and Becker (5) followed this lead but failed to produce infection on *Berberis* or *Mahonia* with teliospores of *P. striiformis*. Due to these failures and a fact that the fungus reproduces asexually through urediniospores that can sustain itself clonally by re-infecting the telial hosts, the existence of an alternate host for *P. striiformis* in nature has been doubted (6).

In June 2009, we observed severe aecial infection on *B. chinensis*, and light infections on *B. koreana* and on 'Emerald Carousel', an interspecific hybrid between *B. koreana* and *B. thunbergii*. Preliminary inoculation on grasses using aeciospores resulted in infection only on *Poa pratensis*, producing uredinia typical of stripe rust caused by *P. striiformis*, suggesting that *Berberis* spp. might be an aecial host of this rust fungus. We report the identification of aecial hosts of *P. striiformis* f. sp. *poae*, and the elucidation of the complete life history of *P. striiformis* f. sp. *tritici*.

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chamber was intermittently misted to ensure high humidity (≈100% relative humidity) and maintain free moisture on leaf surfaces. After inoculation, plants were maintained in a growth chamber at 18 to 20°C with a photoperiod of 12 h.

Inoculation on *Berberis* spp. using telia of *P. striiformis* f. sp. *tritici*. Wheat straw bearing telia of *P. striiformis* f. sp. *tritici* was harvested from an experimental field at the University of California, Davis (CA). Leaf tissue was soaked in water for 24 h, rinsed thoroughly, and maintained moist by wrapping in moistened paper towel. Teliospore germination was monitored by plating teliospores onto water-agar plates and periodically observing the plates under a microscope. When teliospore germination was detected (usually 48 h after plating), straw was suspended over plants of *B. chinensis*, *B. holstii*, *B. koreana*, and *B. vulgaris*, and plants were incubated for 4 days in a mist chamber with a diurnal temperature regime (12-h night at 12°C and 12-h day at 15°C). After inoculation and incubation, plants were maintained in a growth cabinet at the same diurnal temperature/light regimes.

Inoculation on Line E wheat using resultant aeciospores produced on *B. chinensis*. Leaves of *B. chinensis* bearing aecia from telial inoculation were placed onto a piece of filter paper saturated with water in a petri plate for 6 h to promote the release of aeciospores. Water drops were placed onto aeciospore masses to make an aeciospore suspension. Seedlings of Line E wheat

Resistance in U.S. Wheat to Recent Eastern African Isolates of *Puccinia graminis* f. sp. *tritici* with Virulence to Resistance Gene *Sr31*

Y. Jin, USDA-ARS Cereal Disease Laboratory, University of Minnesota, St. Paul; and R. P. Singh, CIMMYT, Apdo, Postal 6-641, Mexico D.F., Mexico

ABSTRACT

Jin, Y., and Singh, R. P. 2006. Resistance in U.S. wheat to recent eastern African isolates of *Puccinia graminis* f. sp. *tritici* with virulence to resistance gene *Sr31*. Plant Dis. 90:476-480.

The stem rust resistance gene *Sr31* derived from rye has been used as an important source of stem rust resistance in many wheat cultivars worldwide. Isolates of *Puccinia graminis* f. sp. *tritici* with virulence to *Sr31* were wheat lines with *Sr31* was obse Uganda in 1999 and an isolate co used in the rust evaluations. Sele wheat from the United States were TTKS was detected in major clas spring wheat, 48% of hard red wi ferred resistance in the spring whe Ivan was likely due to *Sr24*. Resi due to *Sr24*, and resistance in soft 1AL.1RS translocation present in with the eradication of the alt common barberry (*Berberis v* the Midwest and northern Great brought the disease under contr of host resistance was also worldwide. The stem rust resis *Sr31*, derived from Petkus rye been used worldwide in spring, and winter wheat through the use of Russian and other East

differential set of North America (12), were used for evaluating the wheat lines. Two Pgt isolates of races TPMK and TTTT, representing broad virulence in the North American stem rust population, were included for comparisons of infection

Stem rust of common wheat *aestivum*) and durum (*T. turgi durum*), caused by *Puccinia gra tritici* (Pgt), historically was most destructive wheat disease cant losses occurred in the pas disease developed into epiden tions in wheat crops (10). The u tive resistance in major wheat regions in North America, in c to the countries in Afr TTKS in the adapted germ plasm wheat.

Corresponding author: Y. Jin E-mail: yuejin@umn.edu

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DISEASE NOTES

Emergence of Virulence to *SrTmp* in the Ug99 Race Group of Wheat Stem Rust, *Puccinia graminis* f. sp. *tritici*, in Africa

M. Patpour, M. S. Hovmøller, and A. F. Justesen, Aarhus University, Flakkebjerg, 4200 Slagelse, Denmark; M. Newcomb and P. Olivera, University of Minnesota, Department of Plant Pathology, St. Paul, MN, USA; Y. Jin and L. J. Szabo, USDA-ARS, St. Paul, MN, USA; D. Hodson, CIMMYT- Ethiopia, Addis Ababa, Ethiopia; A. A. Shahin, Plant Pathology Research Institute, Sakha, Kafrelsheikh 33717, Egypt; R. Wanyera, KALRO Plant Breeding Research Center, Njoro, Kenya; I. Habarurema, Rwanda Agriculture Board (RAB), P.O. Box 5016 Kigali, Rwanda; and S. Wobibi, BZARDI, P.O. Box 1356, Mbale, Uganda.

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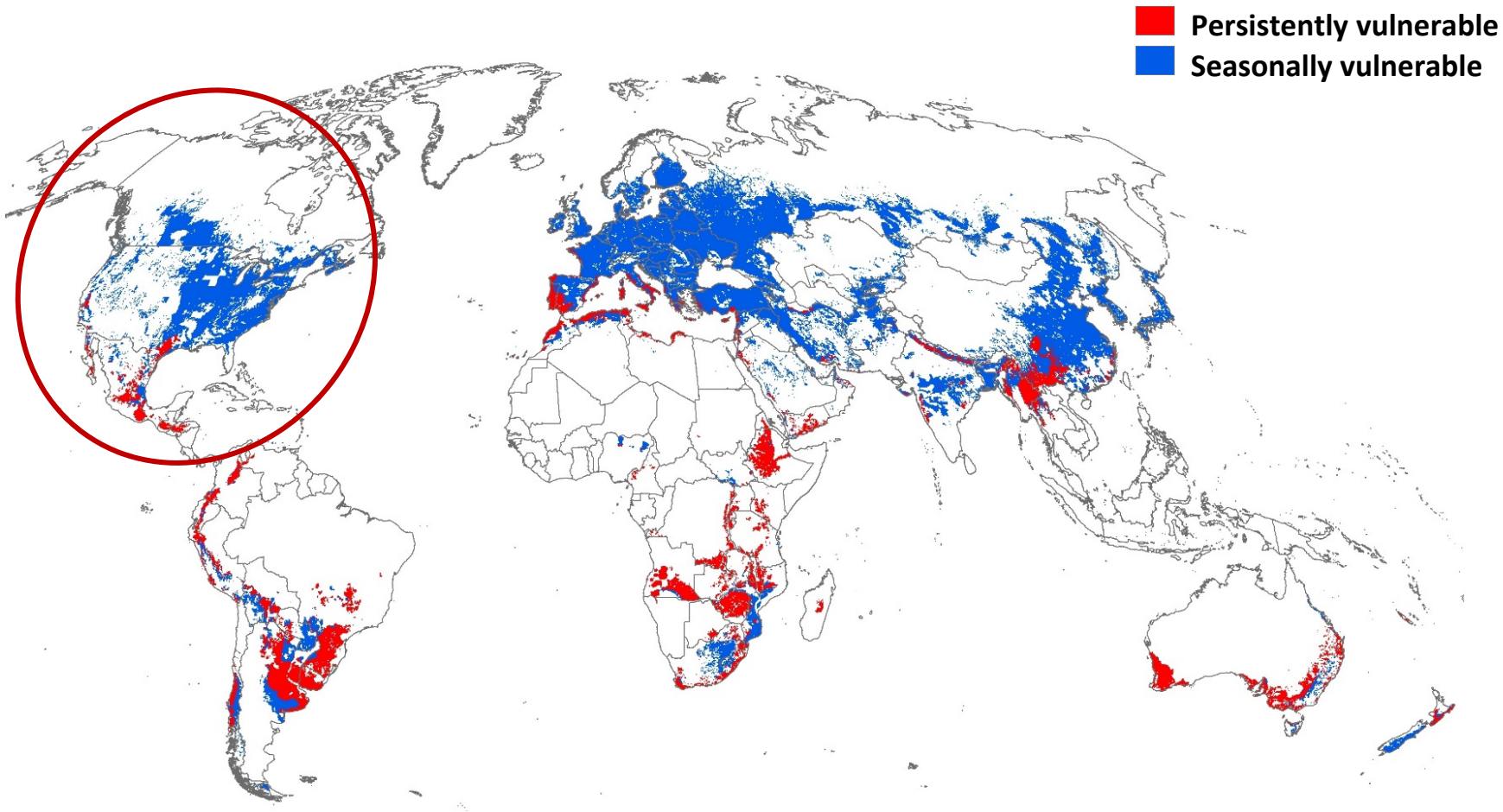
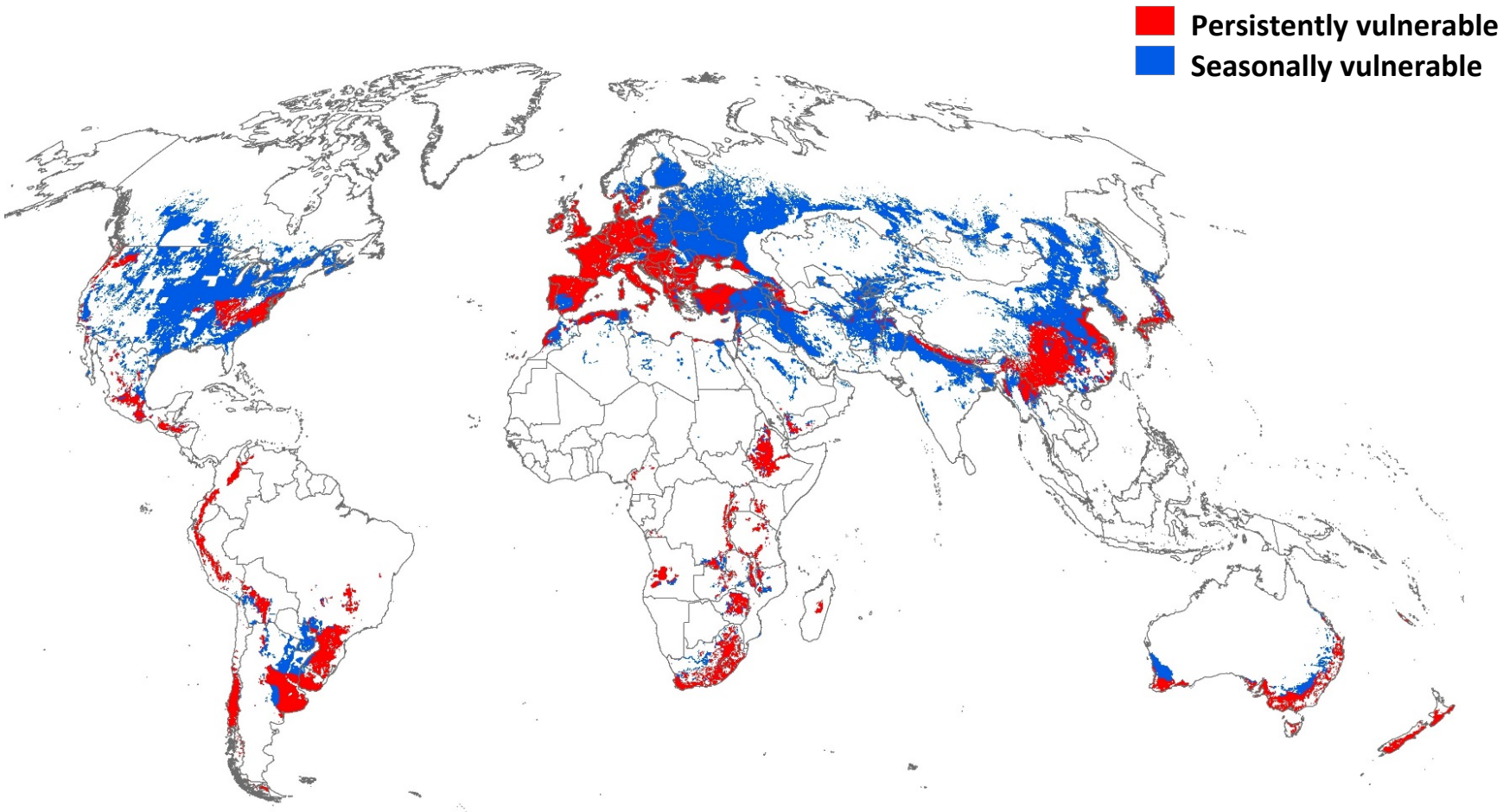
US Wheat Rust Research in a Global Setting

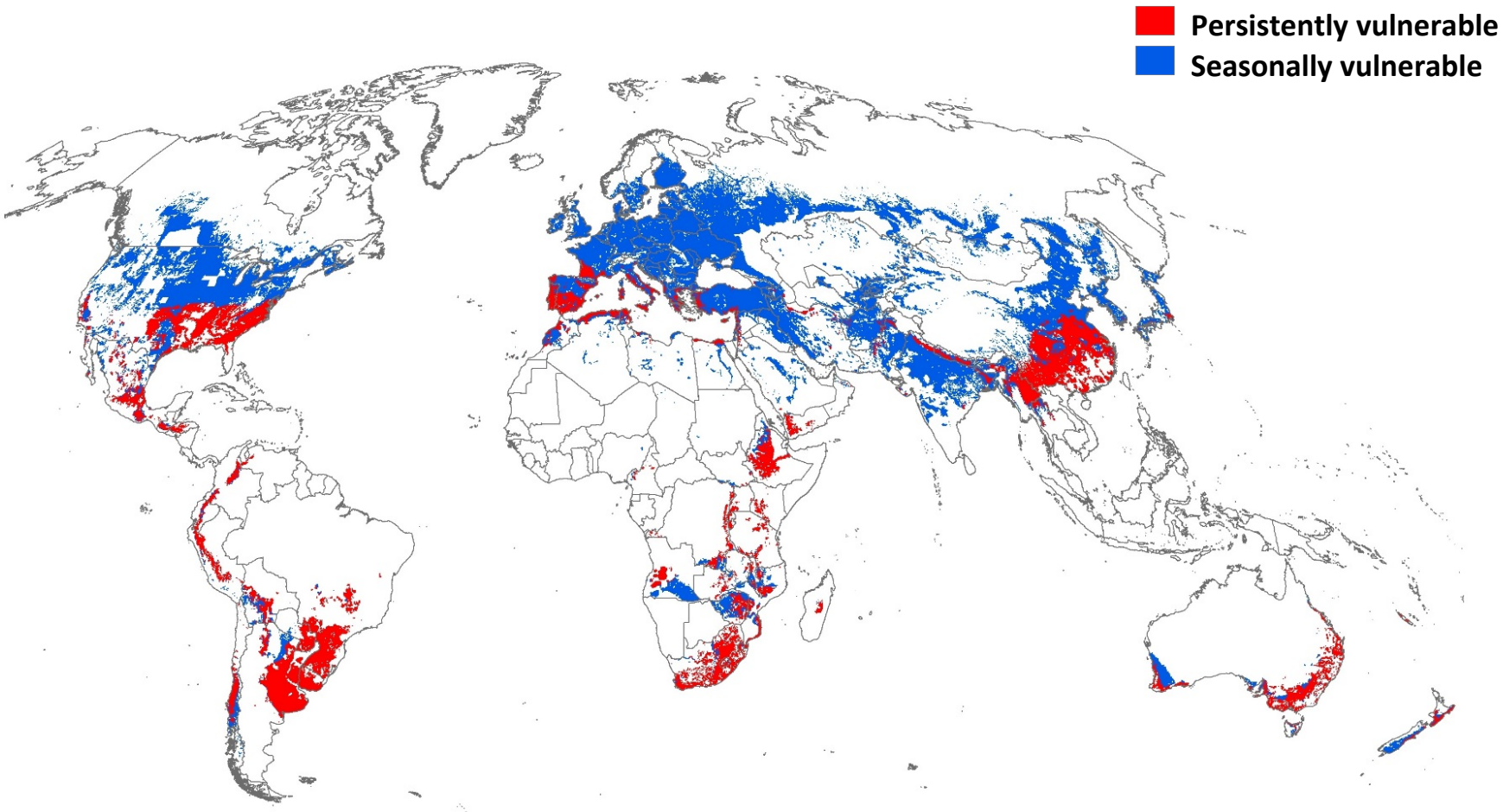
Stem Rust Climate Suitability



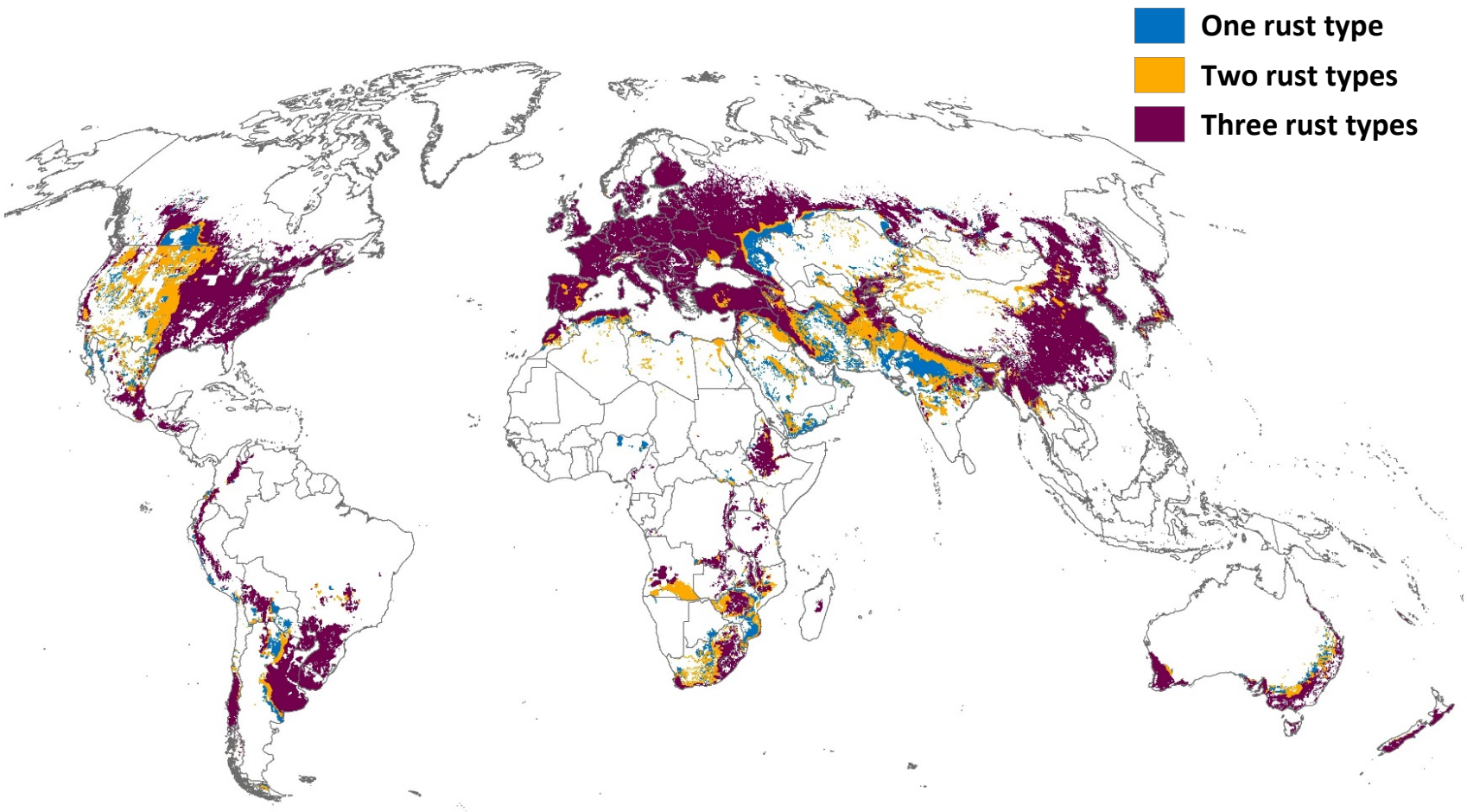
Stripe Rust Climate Suitability



Leaf Rust Climate Suitability



Three Rusts—Seasonally Vulnerable



Note: Suitability prediction based on growth index (GI) values from the CLIMEX model

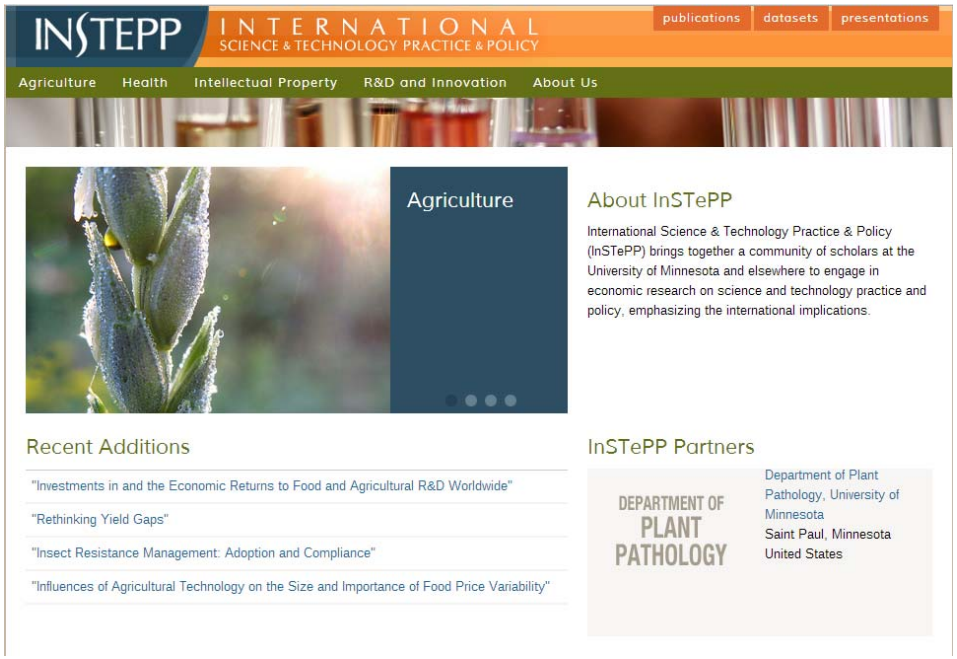
Vulnerability to Wheat Rusts Worldwide

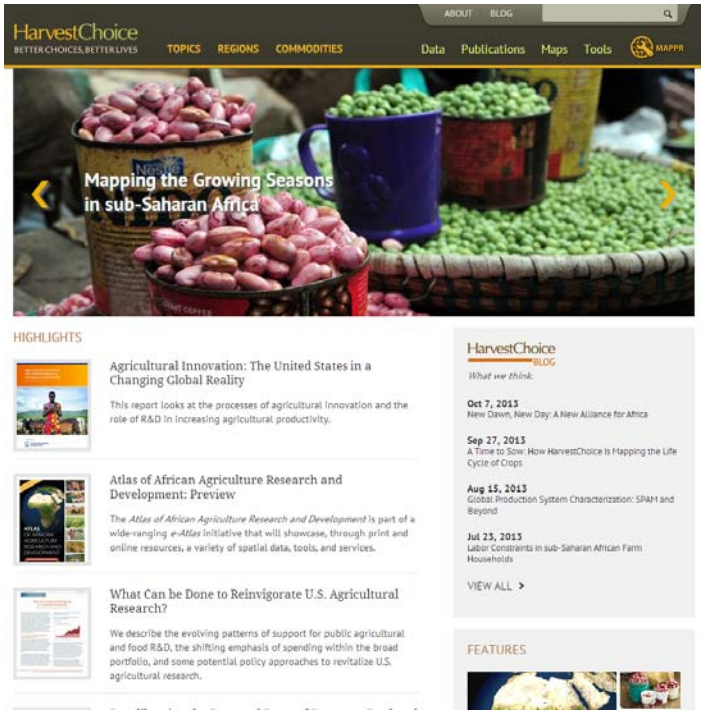
	Stem, Leaf and Stripe Rust Vulnerability			
	None	Only One	Only Two	All Three
	(Percentage of output, all farms)			
Western Europe	0.0	0.0	0.7	99.2
North America	2.2	12.5	37.1	48.3
Australia	0.0	10.3	17.8	71.9
Sub-Saharan Africa	11.0	3.6	13.9	71.6
China	0.0	0.0	11.5	88.5
India	6.3	18.8	72.5	2.5
World	3.2	6.9	27.1	62.7

Concluding Remarks

- U.S. losing considerable global market share in terms of (public) R&D spending
- R&D likely to remain highly spatially concentrated
  - A growing disconnect between the geography of agricultural demand and the location of agricultural R&D performance
- Shift towards more contestable and project-oriented (often shorter-term) funding of public science
  - The problems are just as hard as they ever have been
  - The present returns are just as high (pointing to persistent underinvestment)
- Requires political will to think long term and reinvest and revitalize agricultural R&D in the U.S. and elsewhere in the world (especially among the poorer countries)

Thanks!





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