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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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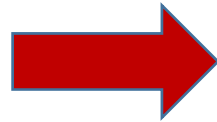
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Outline

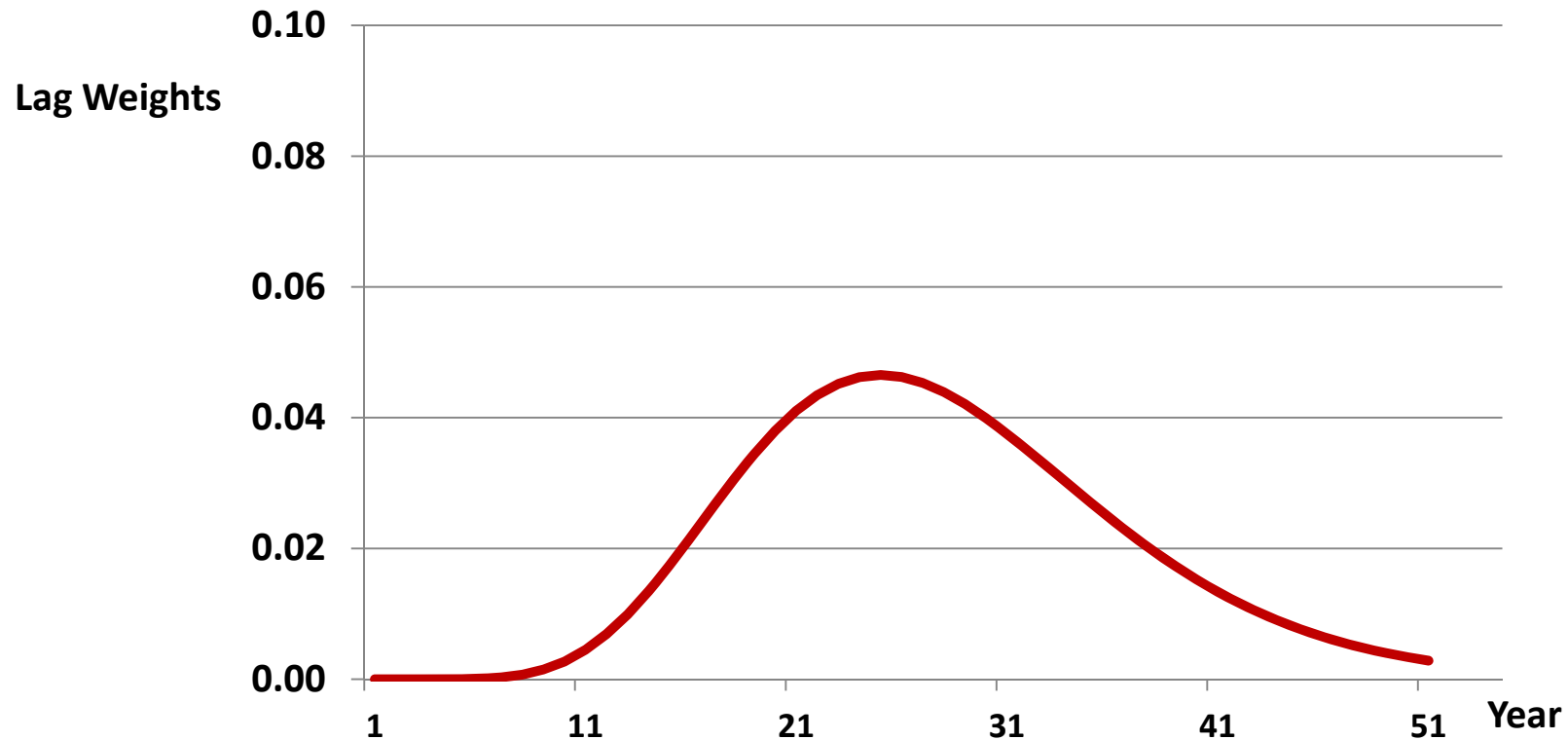
- Persistence Pays! – R&D and Adoption Lags
- Changing Food and Agricultural R&D Realities Worldwide
- U.S. Agricultural Innovations in a Global Context
 - The Case of Wheat Rusts

From Innovation Investment to Adoption and Impact

**R&D
Investments**

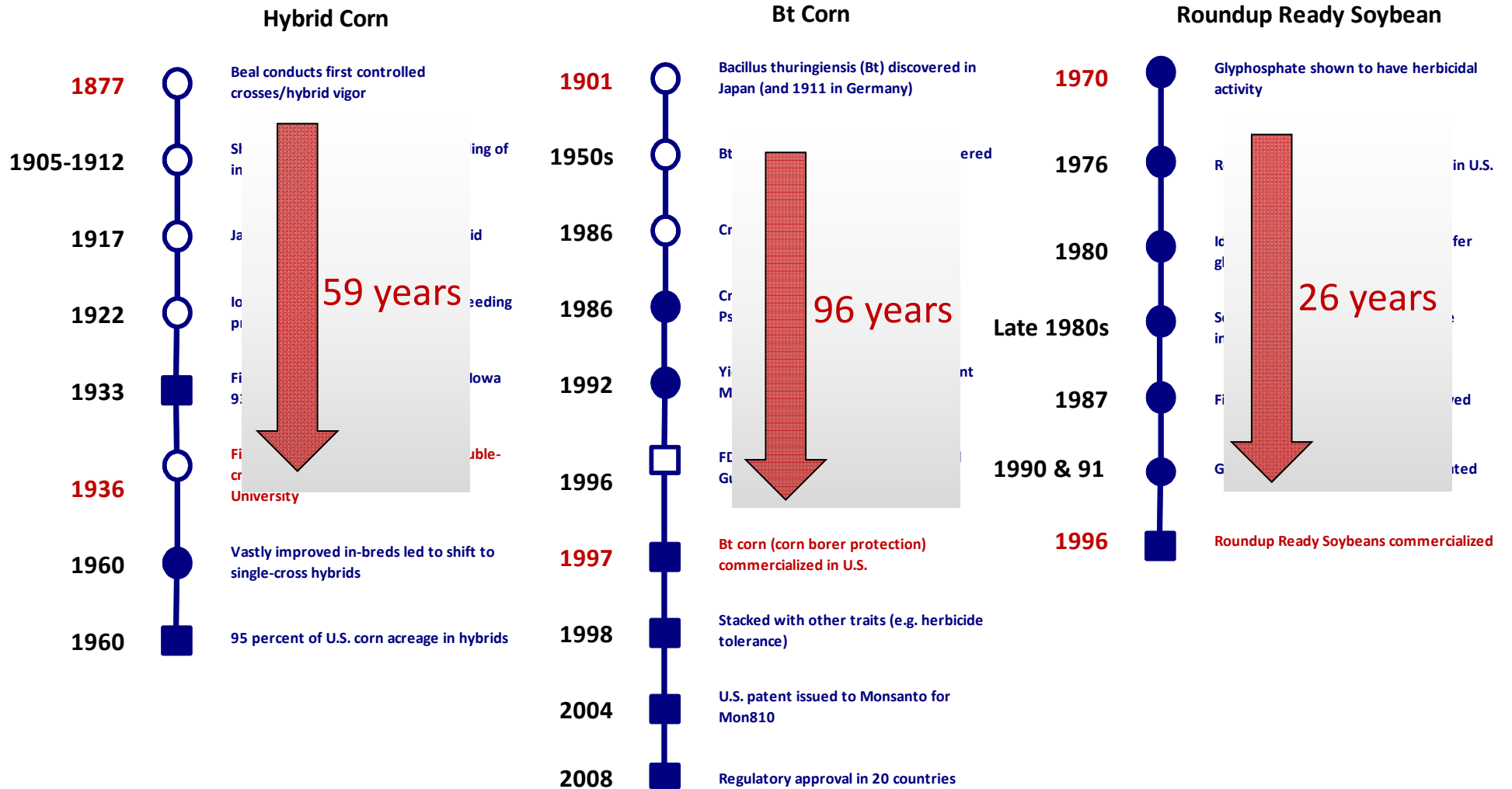


**Farm Productivity
Growth**



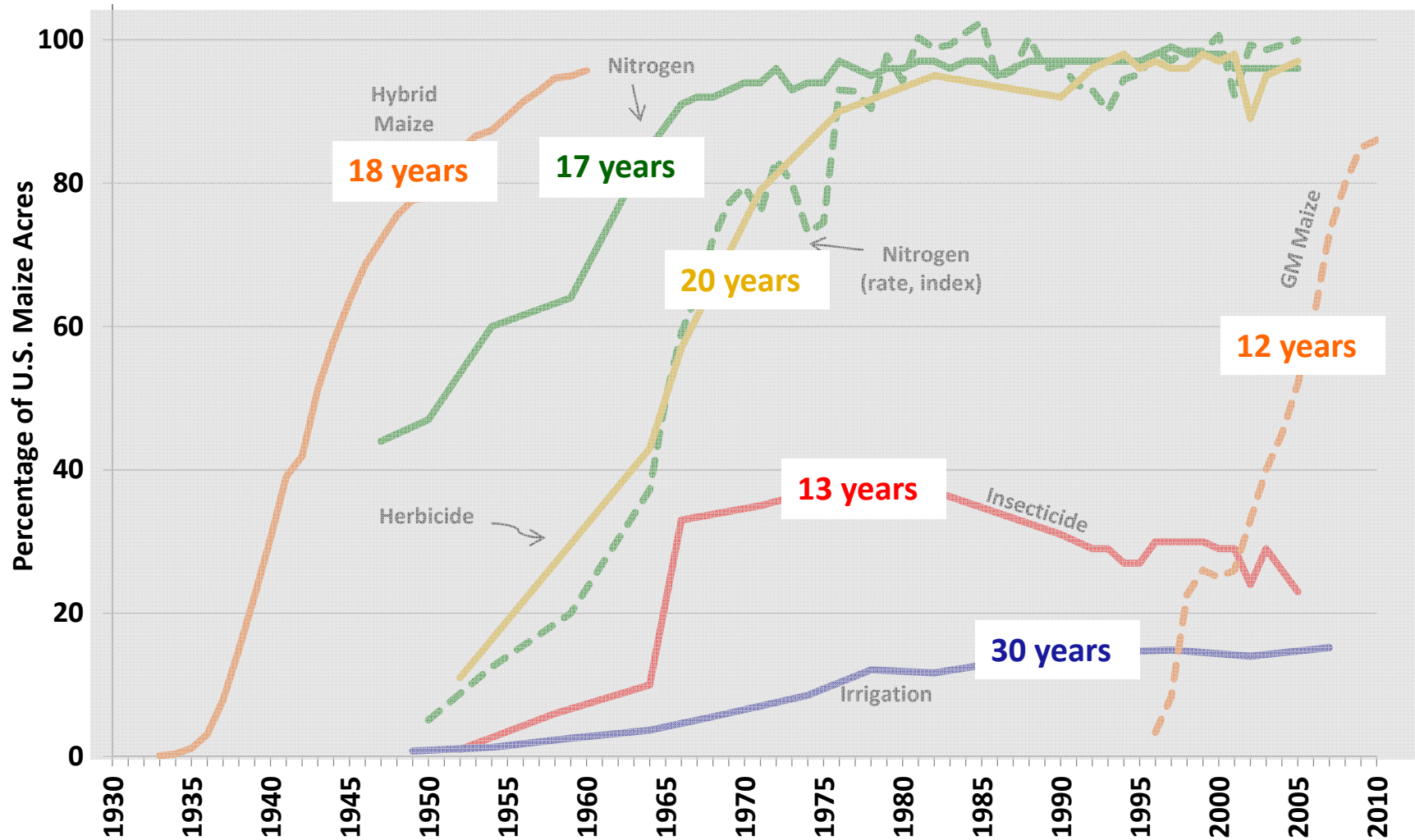
Source: Alston, Anderson, James and Pardey (2010, 2011)

Illustrative Technology Timelines (US)



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

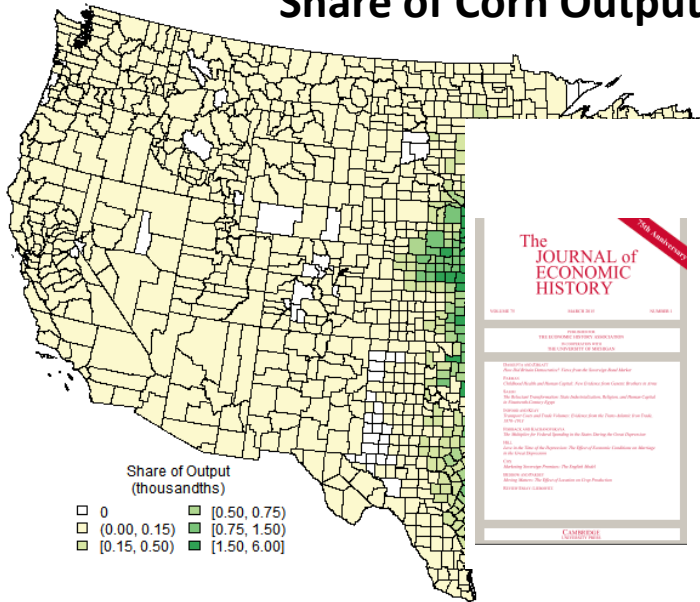
U.S. Maize Technology Adoption Lags



Source: Beddow (2012)

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

Share of Corn Output by County, 1899



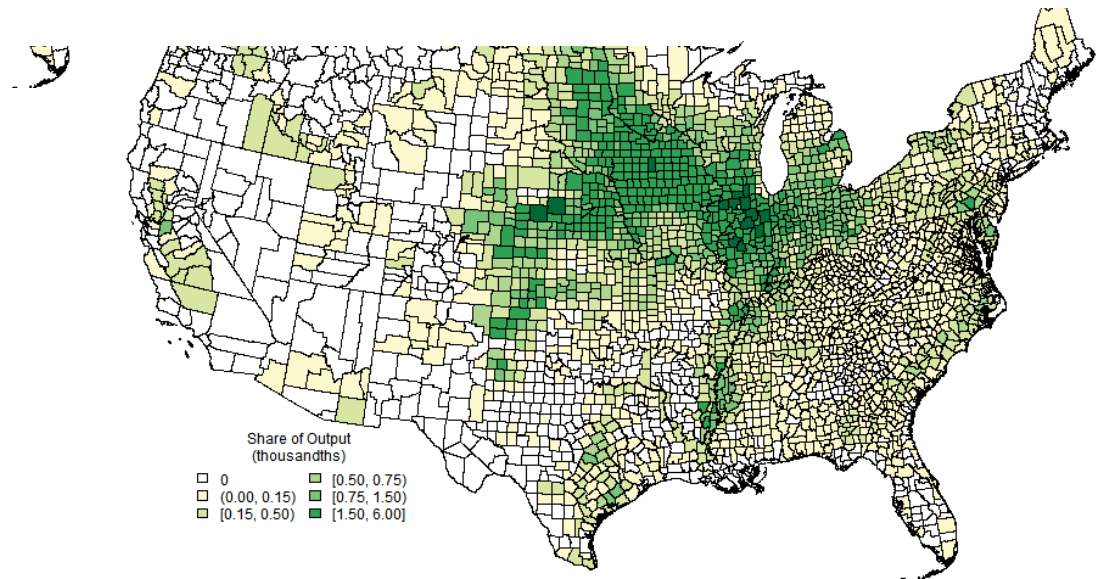
Moving Matters

279 kilometers north

342 kilometers west

16 to 21 percent of corn output growth

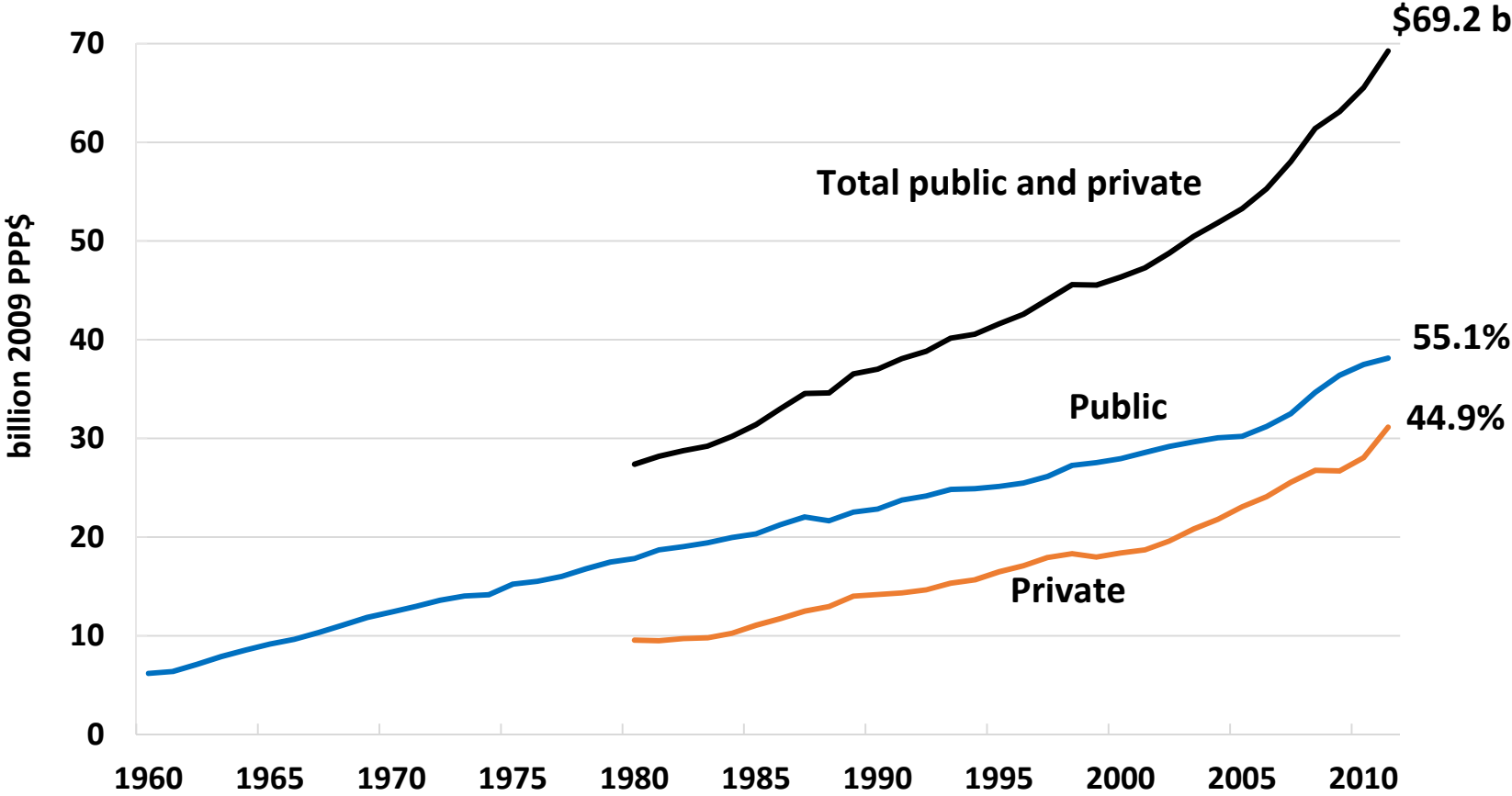
ut by County, 2007



Shifting Ground

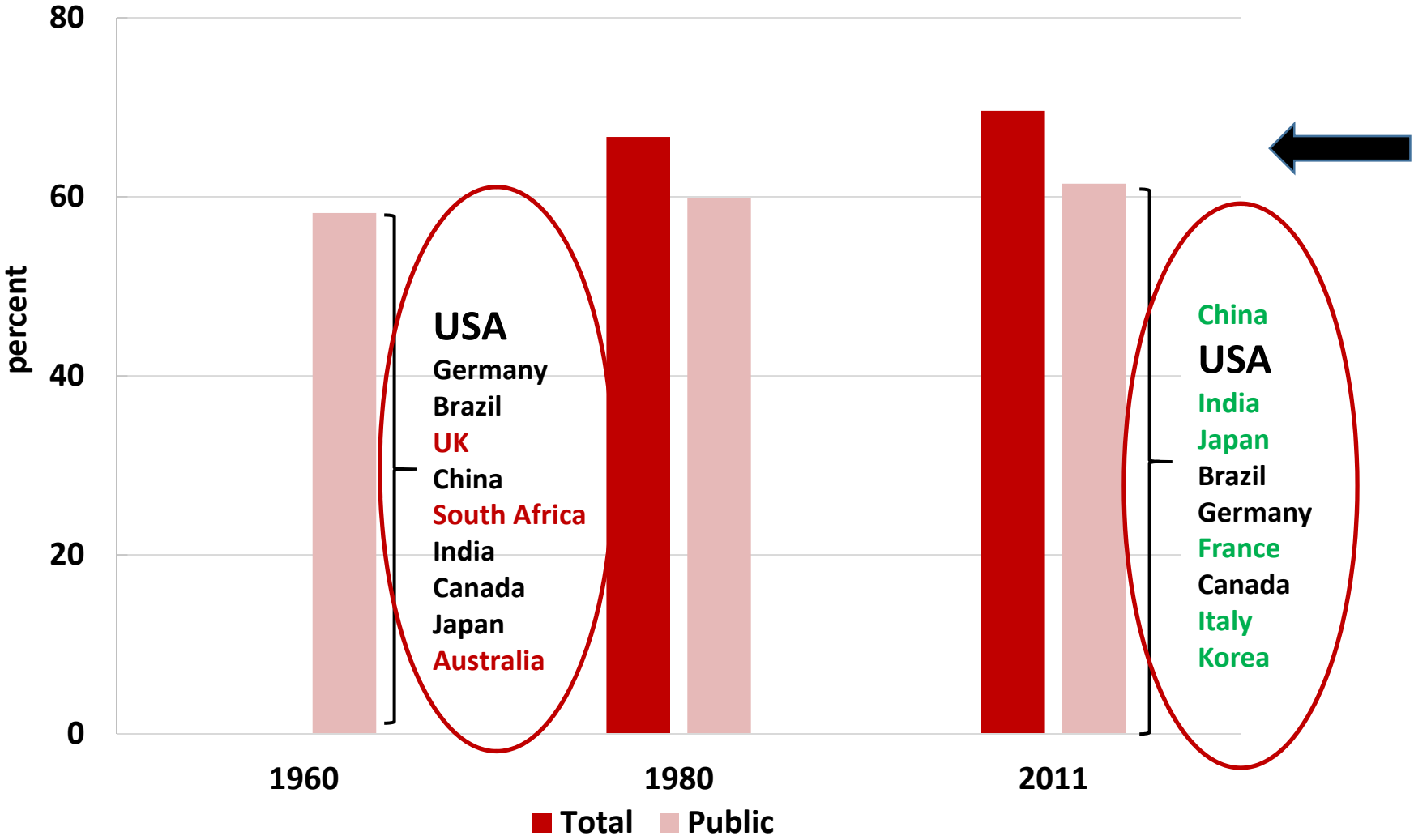
The Global Food and Agricultural R&D Landscape

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

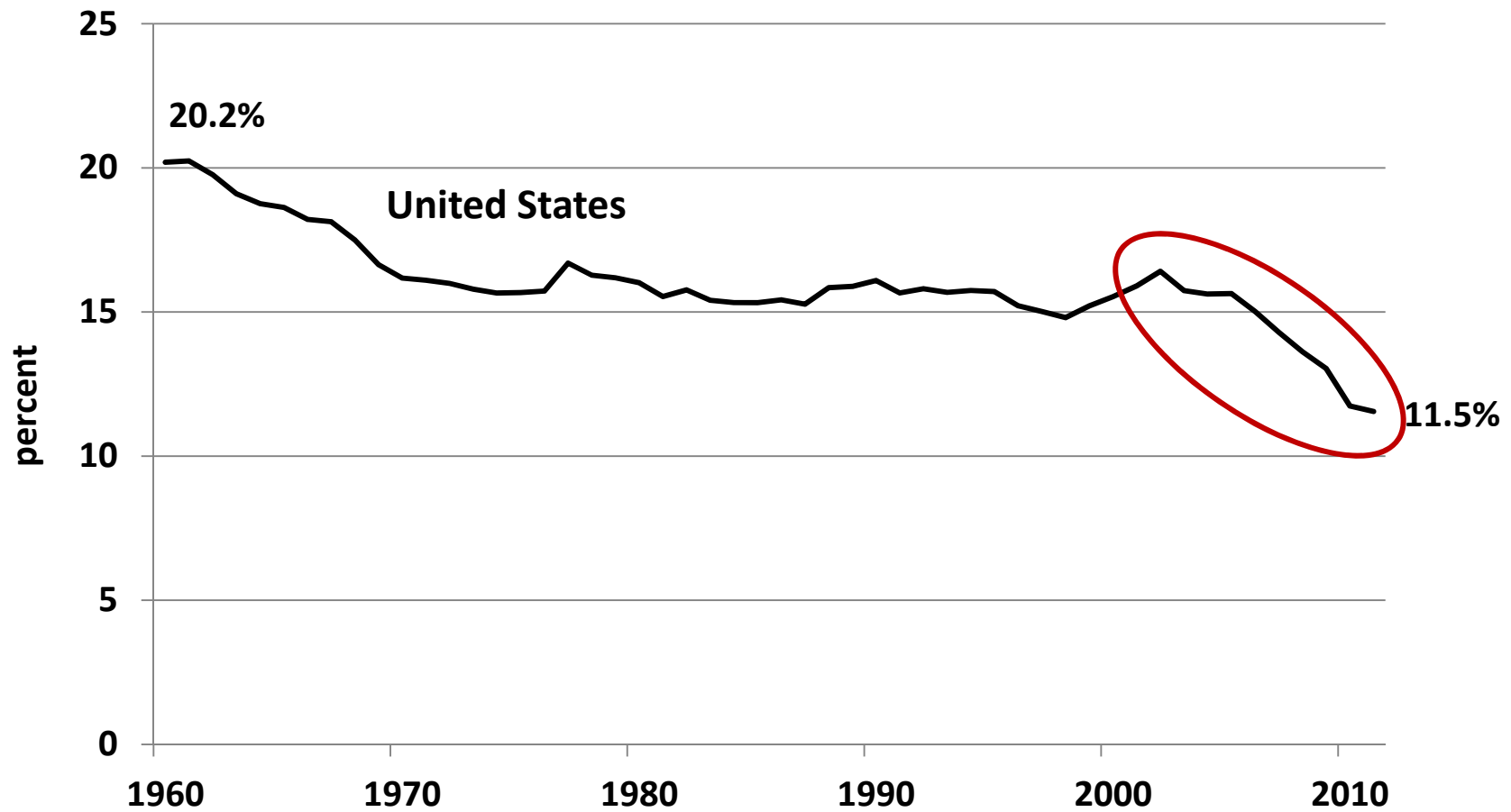


Source: Pardey, Chan-Kang, Beddow and Dehmer (2016, in process)

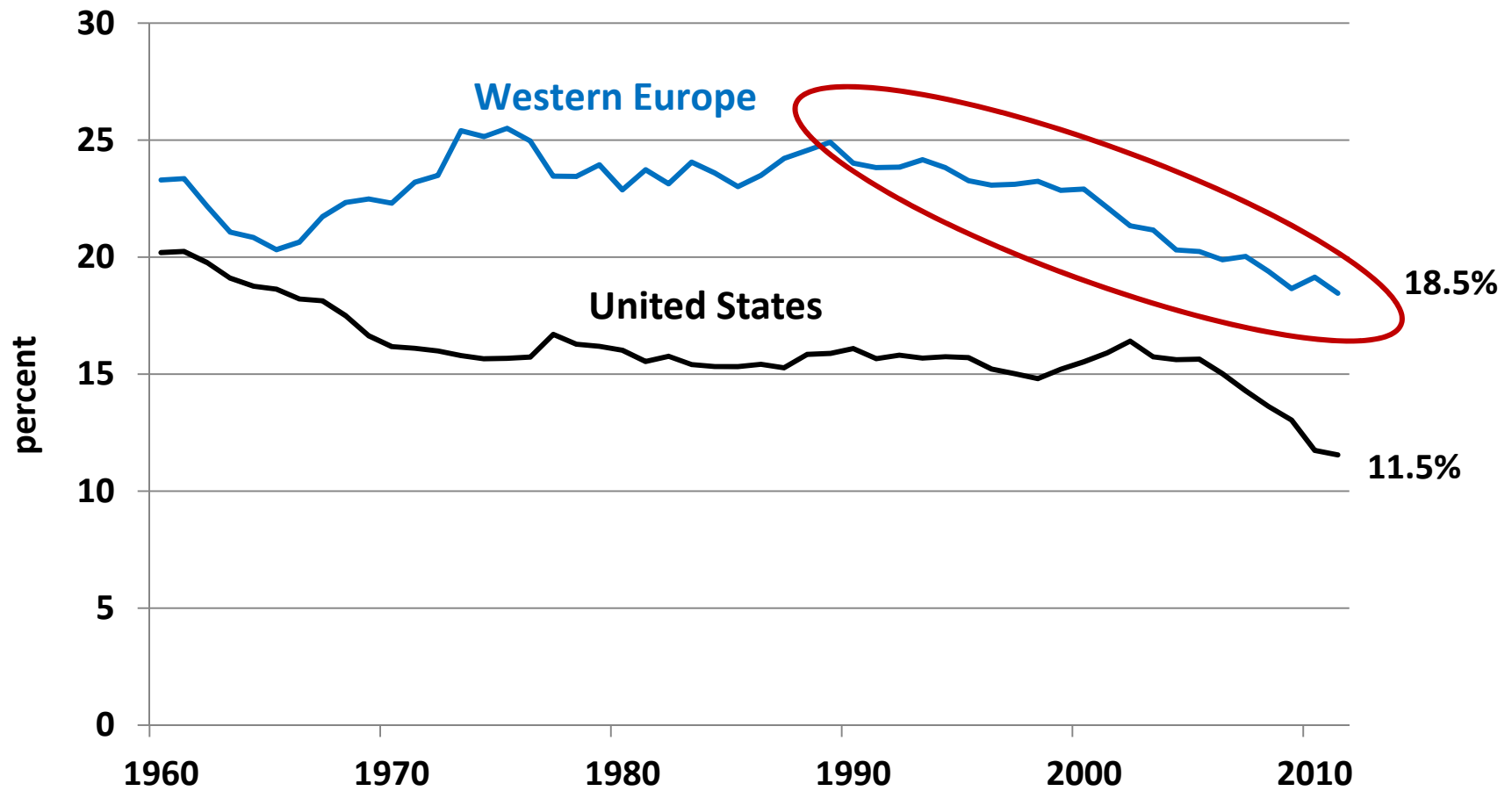
Spatial Concentration -- Top 10 Country Share and Rank



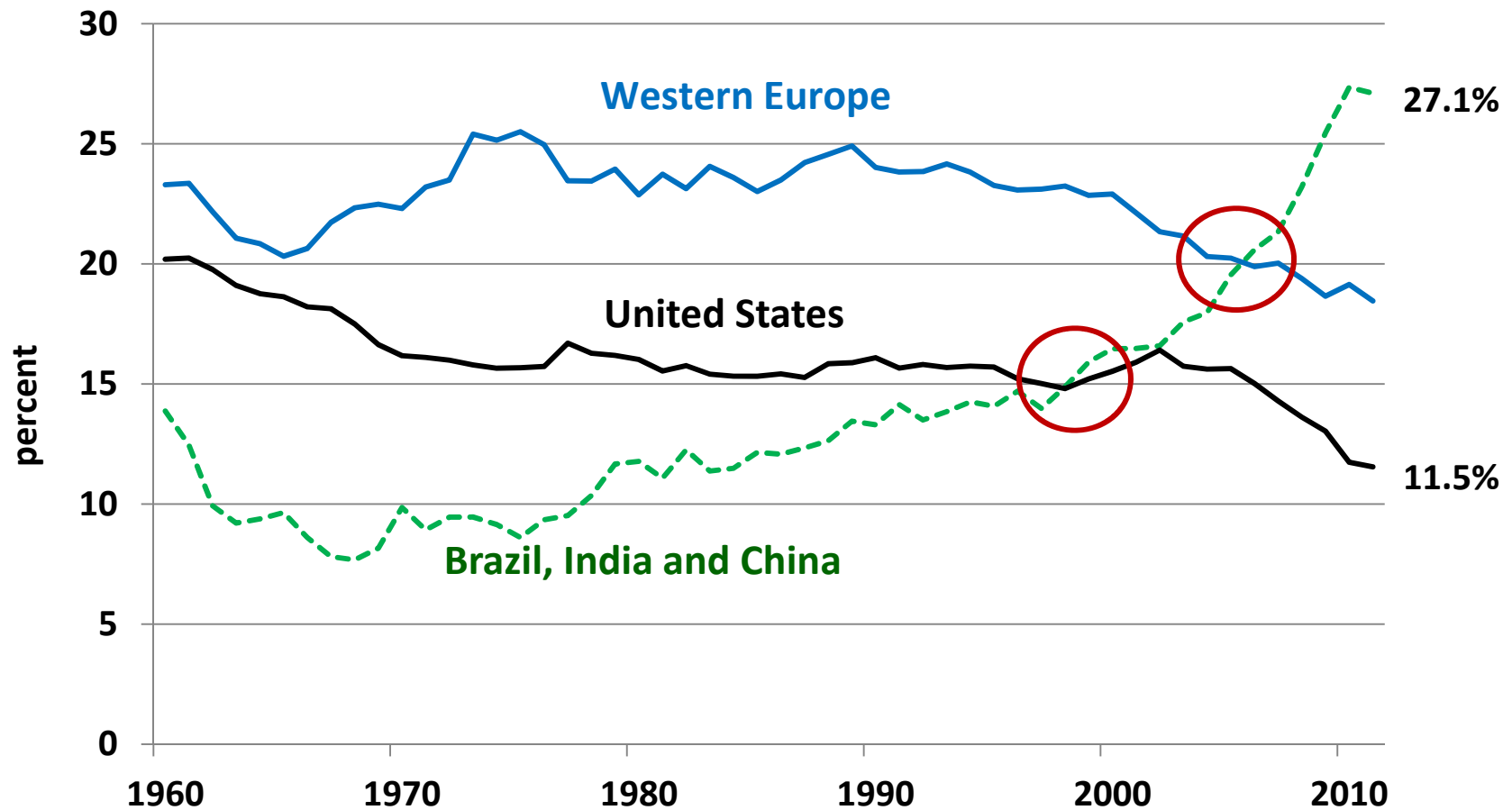
Shifting Global Shares of Public Food & Ag R&D, 1960-2011



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



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



Agricultural R&D, Innovation and Adoption

Sustainable Productivity Performance

- Economic challenges
 - Comparative advantage and international competitiveness

- 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



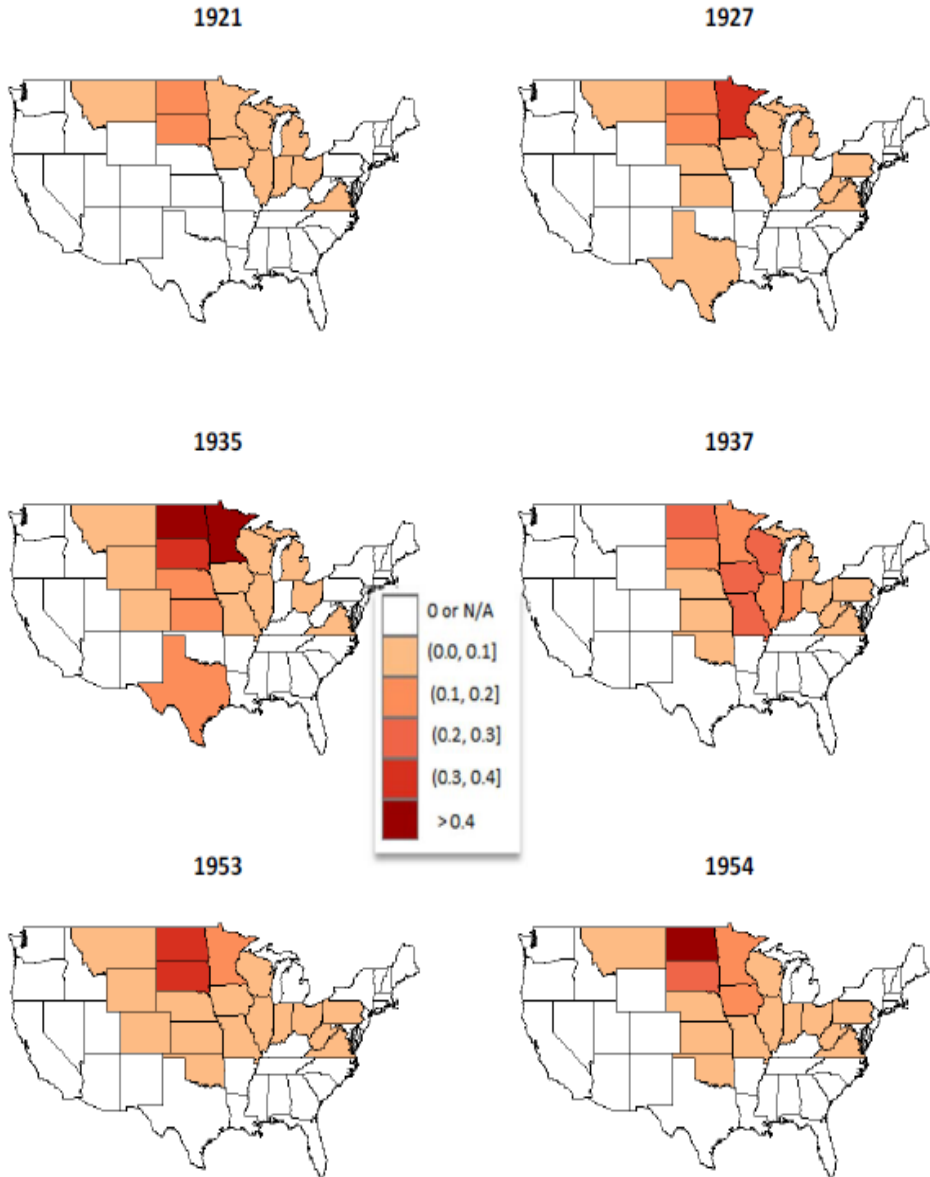
Stripe Rust



Leaf Rust

Stem Rust

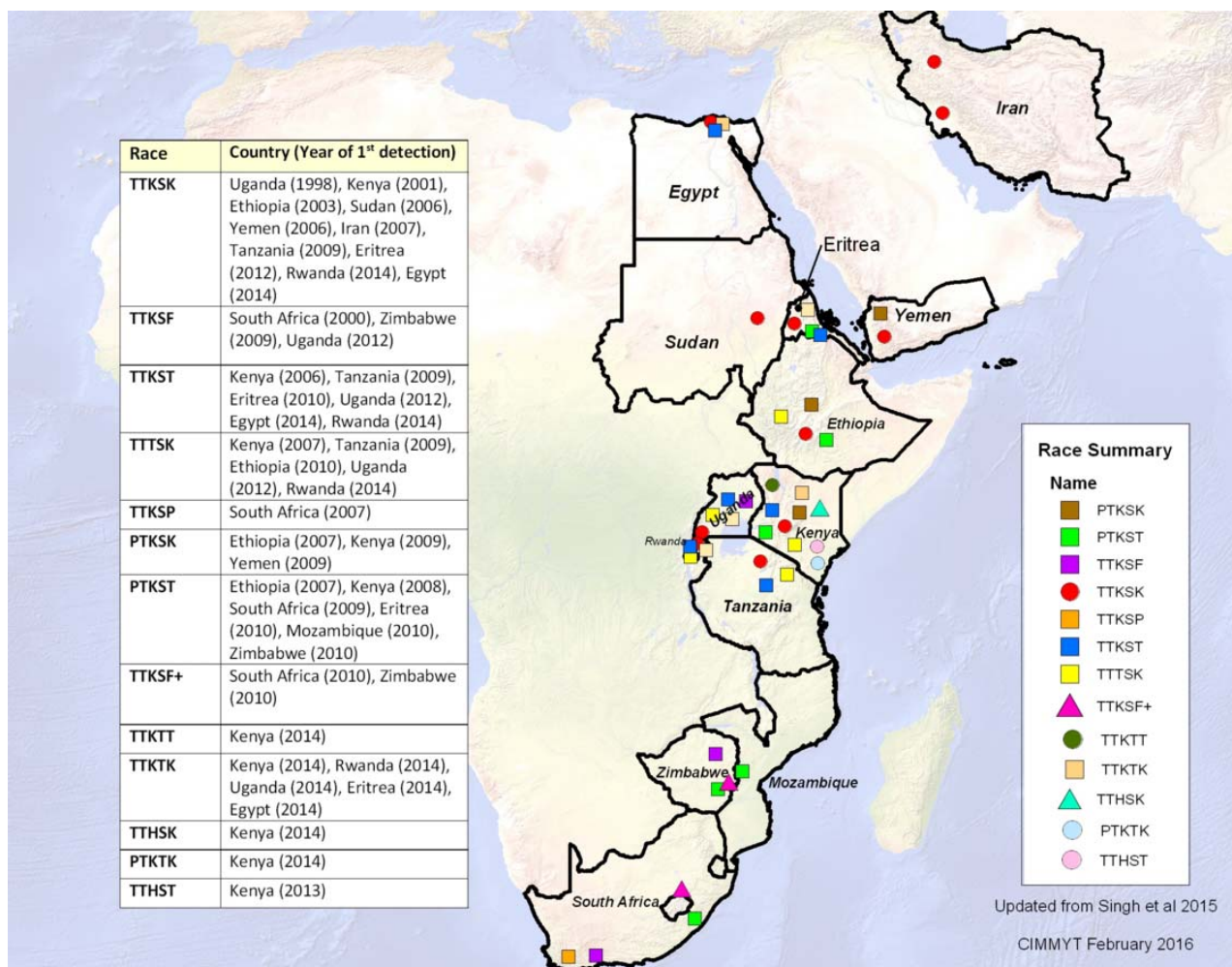
Appendix Figure 1: Reported State Losses (share) Due to Stem Rust in the U.S., Selected Years.



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



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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

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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. Wanayera, M. Kinyya, and P. Njau, Kenyan Agricultural Research Institute, National Plant Breeding Research Center, P.O. Njoro, Kenya; T. Feteh, 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

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. Feteh, Jr., Cereal Research Center, 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 Feteh, T. Jr. 2006. 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 Sr58; 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 (MCCT, QCCO, BCRS, RTHS, and TPKM) 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 name this variant *Puccinia graminis* f. sp. *tritici* lineage *TTKS-Sr24*.

monogenic resistant line LeSr24Aa 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, LeSr24Aa, and Agem99LMPG, 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.

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 submerged in a water bath at 43°C for 15 min. After the heat-shock treatment, urediniospores from each sample were cultured on the

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 Govindan¹

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(KARI-NPBR), P.O. Njoro,

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 observed on wheat lines with Sr31 in Uganda in 1999 and an isolate of Sr31 was used in the rust evaluations. Soft wheat from the United States were TTKS was detected in major class spring wheat, 48% of hard red winter resistance in the spring wheat from was likely due to Sr24. Rust due to Sr24, and resistance in soft wheat from the United States were TTKS was detected in major class spring wheat, 48% of hard red winter resistance in the spring wheat from was likely due to Sr24. Rust due to Sr24, and resistance in soft wheat from the United States were TTKS was detected in major class spring wheat, 48% of hard red winter resistance in the spring wheat from was likely due to Sr24. Rust due to Sr24, and resistance in soft wheat from the United States were TTKS was detected in major class spring wheat, 48% of hard red winter resistance in the spring wheat from was likely due to Sr24.



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plant disease
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Emergence of Virulence to SrTm9 in the Ug99 Race Group of Wheat Stem Rust, *Puccinia graminis* f. sp. *tritici*, in Africa

M. Patpour, M. S. Homoller, and A. F. Justesen, Aarhus University, Flakkebjerg, 4200 Slagelse, Denmark; M. Newcomb and P. Oliveira, 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. Wanayera, KALRO Plant Breeding Research Center, Njoro, Kenya; I. Habarurema, Rwanda Agriculture Board (RAB), P.O. Box 5016 Kigali, Rwanda; and S. Wobubi, BZARDI, P.O. Box 1356, Mbale, Uganda.



Century-Old Myst with the Ident

U.S. Department of Agriculture-Agricultural Research Service, Cereal Disease Laboratory, University of Minnesota, St. Paul, MN 55108

Jin, Y., Szabo, L. J., and Carson, M. 2010. *Puccinia striiformis* life history solved with the an alternate host. *Phytopathology* 100:432-435.

The life history of *Puccinia striiformis* remains elusive. It has been identified on wheat and grasses, but its alternate host has never been identified. Inoculations from naturally infected *Berberis* resulted in infection on *Poa pratensis*, producing rust caused by *P. striiformis*. Analyses using re-sequencing and DNA sequence confirmed the rust *Puccinia* and acia were produced on *B. chinensis*.

Life histories (or life cycles) of most rust crops and grasses have been well understood for centuries. The life history of *Puccinia striiformis*, an organism of stripe (or yellow) rust of impo grasses, remains a mystery because the alternate host *P. striiformis* has never been identified. It is assumed that *P. striiformis* is a macrocyclic based on similarities with other cereal rusts. The alternate host by infecting a species with germinating teliospores of *P. striiformis* (Mains (10) suspected *Berberis* an alternate host of *P. striiformis* because *P. helvetica*, *P. arvensis*, and *P. monilioides* 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 acial infection on *B. chinensis*, and light infections on *B. koronaria* and 'Emerald Cascade', an interspecific hybrid between *B. koronaria* and *B. thunbergii*. Preliminary inoculation on grasses using ascospores resulted in infection only on *Poa pratensis*, producing uredinia typical of stripe rust caused by *P. striiformis*, suggesting that *Berberis* spp. might be an acial host of this rust fungus. We report the identification of acial hosts of *P. striiformis* f. sp. *tritici*, and the elucidation of the complete life history of *P. striiformis* f. sp. *tritici*.

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0066-4286/11/0908/0465\$20.00

Keywords

Triticum aestivum, *Puccinia graminis* f. sp. *tritici*, rust

Abstract

Race Ug99 of the fungus black rust disease on wheat races belonging to the U to various wheat-growing wild as Zimbabwe, South susceptibility of 90% of group of races was recognized and food security. Its spread to other countries in Africa and Ethiopia has is varieties and breeding material of race-specific resistance enhance the diversity of varieties that yield more than and promoted, major effective varieties with var resistance and mitigate d

chamber was intermittently misted to ensure high humidity (90% 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. koronaria*, and *B. thunbergii*, 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 regime.

Inoculation on Line E wheat using resultant ascospores produced on *B. chinensis*

Leaves of *B. chinensis*. Leaves of *B. chinensis* bearing acia 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 ascospores. Water drops were placed onto ascospore masses to make an ascospore suspension. Seedlings of Line E wheat

Stem rust of common wheat (*Triticum aestivum*) and durum (*T. turgidum*), caused by *Puccinia graminis* f. sp. *tritici* (Pgt), historically was most destructive wheat disease. Recent losses occurred in the past decade developed into epidemic in wheat crops (10). The five resistance in major wheat regions in North America, with the eradication of the alternate common harbors (*Berberis* spp.) in the Midwest and northern Great brought the disease under control of host resistance was also worldwide. The stem rust race Sr31, derived from Pektas rye been used worldwide in spring, and winter wheat through the use of Russian and other East

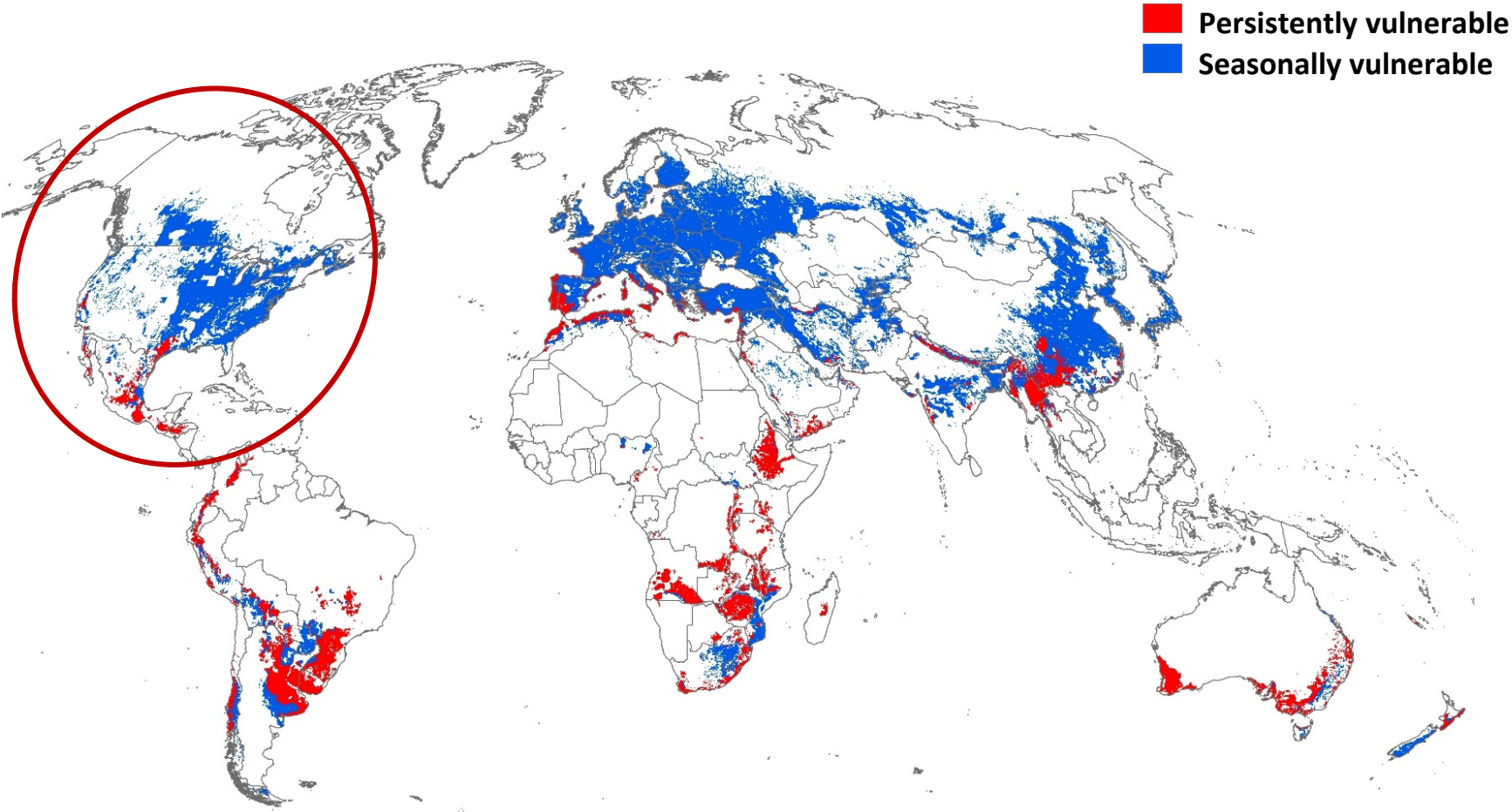
Corresponding author: Y. Jin. E-mail address: yuejin@ars.usda.gov
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476 Plant Disease / Vol. 100, No. 2

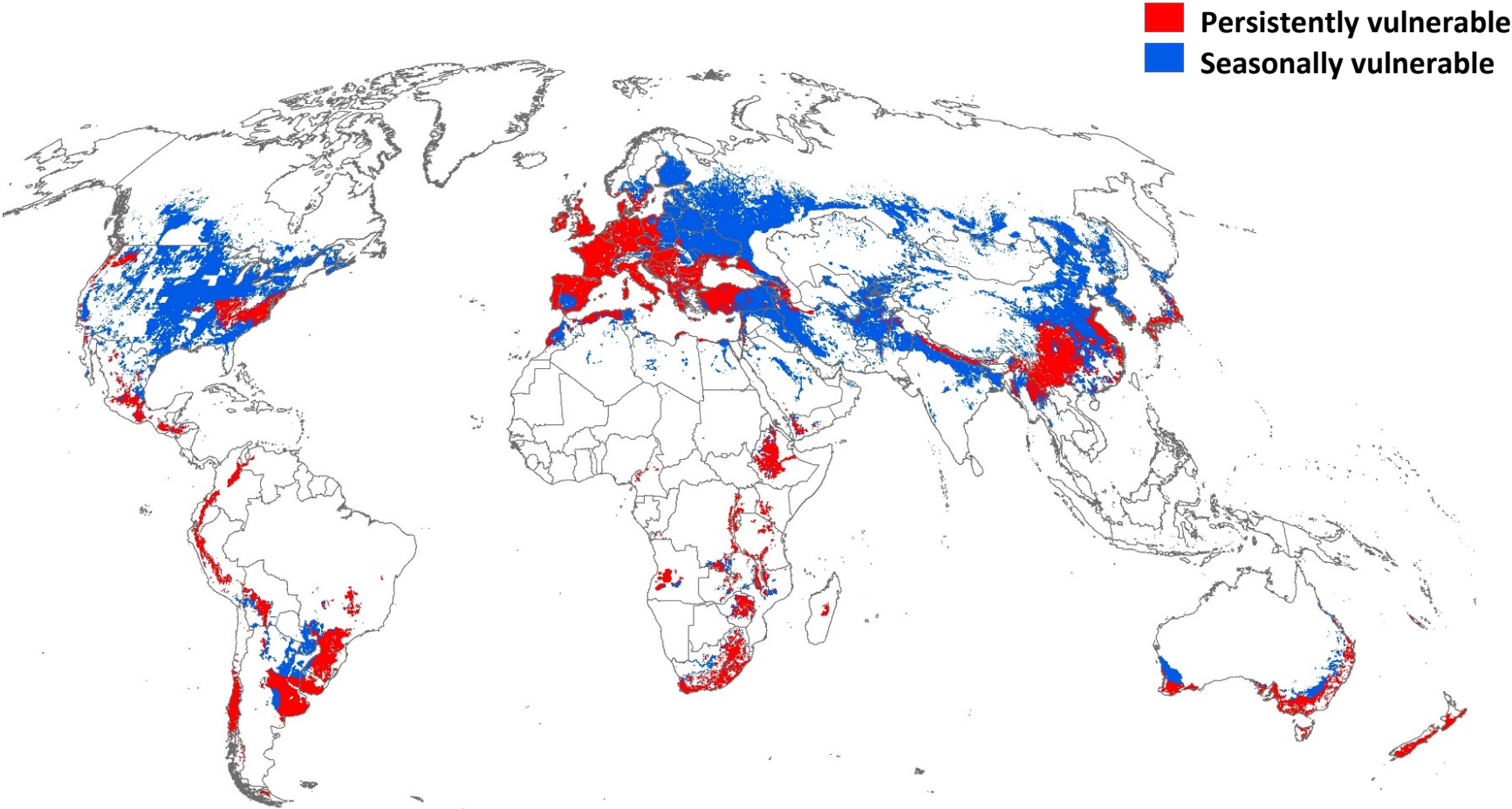
Doing Good by Doing Well

US Wheat Rust Research in a Global Setting

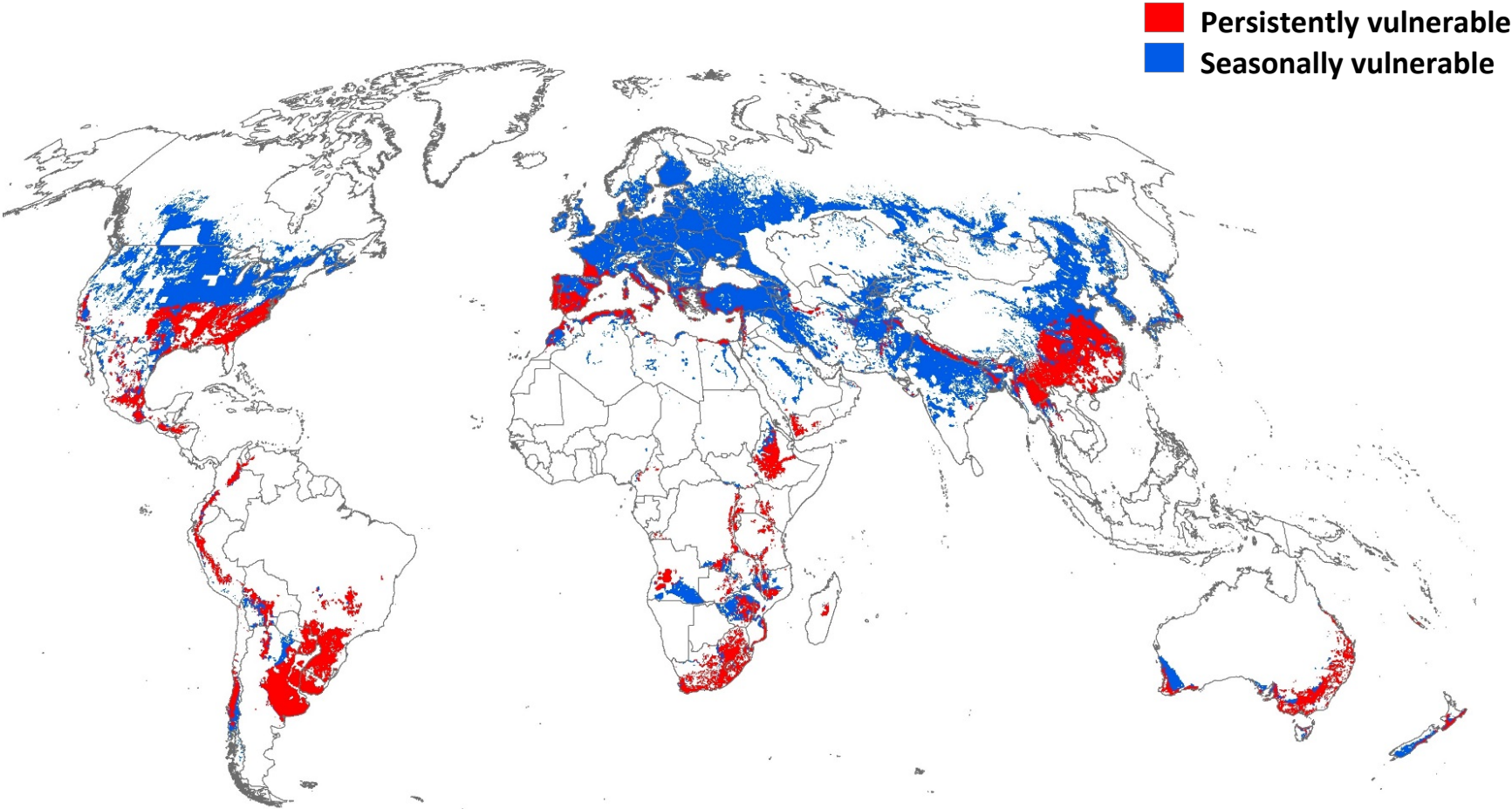
Stem Rust Climate Suitability



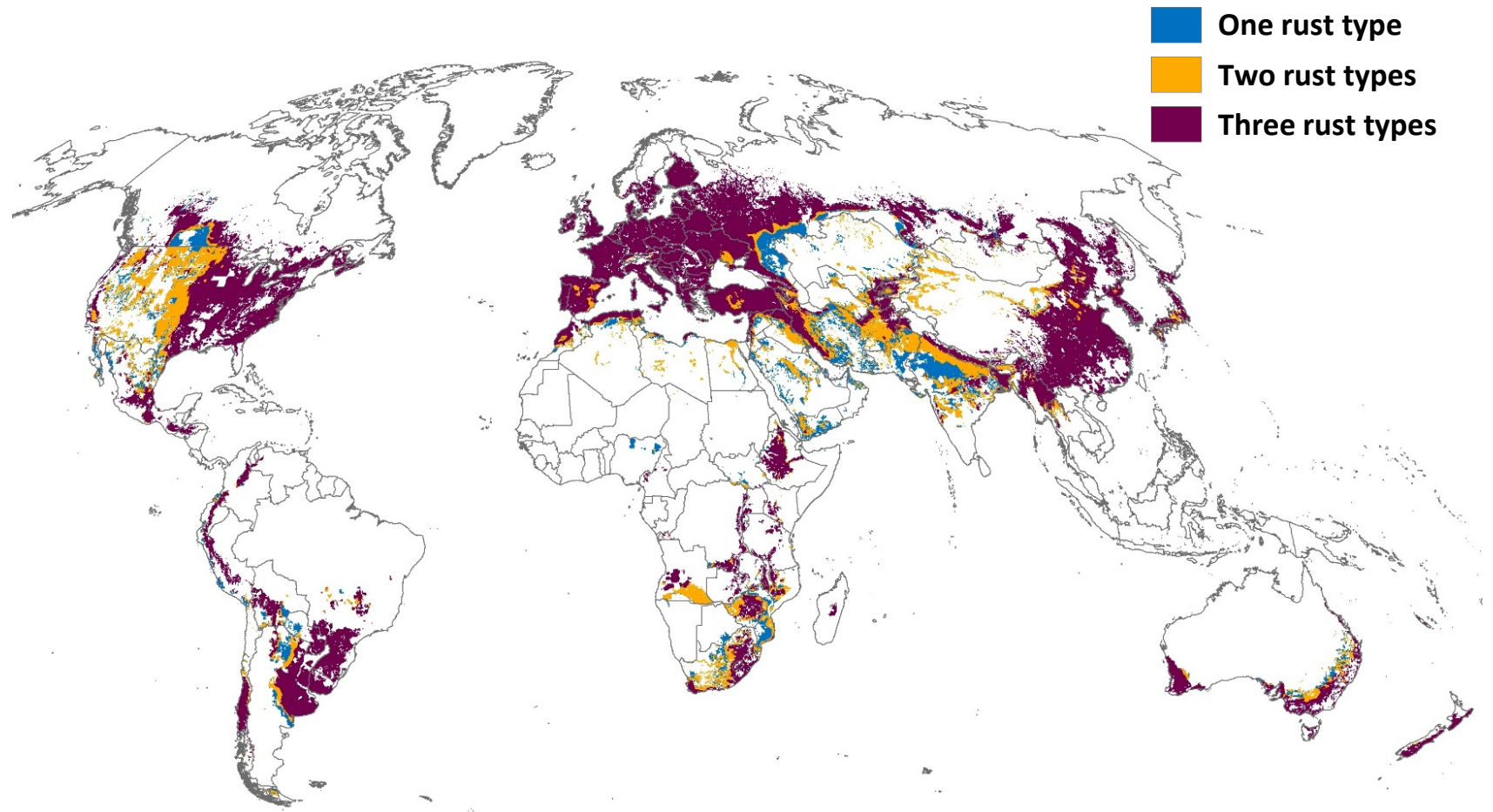
Stripe Rust Climate Suitability



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!

The screenshot shows the InStepp website homepage. The header features the InStepp logo and navigation links for publications, datasets, and presentations. Below the header, there are tabs for Agriculture, Health, Intellectual Property, R&D and Innovation, and About Us. The main content area includes a featured image of a plant stem, a section titled 'Agriculture' with a sub-header 'About InStepp' describing the organization's mission, and a 'Recent Additions' section listing several research papers.

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- "Rethinking Yield Gaps"
- "Insect Resistance Management: Adoption and Compliance"
- "Influences of Agricultural Technology on the Size and Importance of Food Price Variability"



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The screenshot shows the HarvestChoice website homepage. The header features the HarvestChoice logo and navigation links for Data, Publications, Maps, and Tools. Below the header, there is a featured image of a basket of red beans with the text 'Mapping the Growing Seasons in sub-Saharan Africa'. The main content area includes a 'HIGHLIGHTS' section with several articles and a 'FEATURES' section.

HarvestChoice
BETTER CHOICES, BETTER LIVES

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HIGHLIGHTS

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- Atlas of African Agriculture Research and Development: Preview**
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- What Can be Done to Reinvigorate U.S. Agricultural Research?**
We describe the evolving patterns of support for public agricultural and food R&D, the shifting emphasis of spending within the broad portfolio, and some potential policy approaches to revitalize U.S. agricultural research.

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