11.1. Introduction
A technological breakthrough in agriculture often leads to increased yields, or improves the quality of output, or enhances the efficiency of input use. If the new technology has applicability beyond the confines of the location for which it was generated, or beyond the commodity for which it was developed, such an effect is commonly referred to as spillover effects. A review (Deb and Bantilan 2001) of the spillover impacts of agricultural research has covered the evolution of the concept over time, different types of spillovers dealt in literature and techniques to quantify spillover impacts by different studies on the subject.

Bantilan and Davis (1991) identified three types of spillover effects: across-location spillover, across-commodity spillover and price spillover. The first two types are direct effects and the last indirect.

Across-location or across-environment spillover effect refers to a situation where a technology developed for a specific location can be adapted and adopted to improve the production efficiency at other locations. However, the degree of applicability may vary across locations due to agronomic, climatic, ecological and socioeconomic differences in the production environments. Also known as technology spillover, an example of across-environment research spillover is the ICRISAT-developed sorghum variety ICSV 112 (SPV 475). Primarily intended for India, it was later released in India (CSV 13), Mexico (UNAL 1-87), Nicaragua (Pinoleso) and Zimbabwe (SV 1). This variety matures in 115-120 days and yields 3.4 t ha$^{-1}$ at Patancheru, India (ICRISAT 1990).

Evenson (1989) described across-location spillover as interlocational spillover and explained it with a generalization of the role of geoclimatic inhibitors of spillover (Figure 11.1). The horizontal axis depicts an index of a particular set of geoclimatic factors such as water stress. The vertical axis indicates the variable cost of production per unit of product. Suppose that three research programs are located, respectively, in environments 1, 2 and 3. Environment 1 is the “best” suited for production. The technology employed there has been “targeted” to location 1. When this technology is used in environments other than 1, its performance is diminished by environmental interactions. The diminution in performance is greater for the program more tightly targeted to environment 1. Research programs in locations 2 and 3 similarly target technology to their respective environments.

The real cost advantage of the technology developed for environment 1 (relative to the technology for environments 2 or 3) declines when the technology is transferred to locations dissimilar to location 1. Its absolute advantage (over type 2 or 3 technology) is shown to be limited to the range $E_{12}^{-E_{13}}$. Now consider an improvement in technology produced by research in location
Figure 11.1. Generalization of the role of geoclimatic inhibitors of spillover effects (Evenson 1989).

1 (depicted as the $A_1'$ curve). The direct spillover of this technology is limited to the environment range $E'_{21} - E'_{13}$. However, when comparable technology improvements occur in locations 2 and 3, the range of direct spillover from 1 to the other locations would be narrowed. If more locations were to build targeted research programs, the range of direct spillover would be further narrowed. Thus, the specification of direct spillover research requires consideration of the general research design of a system, including the range of locations in which the technology is applicable.

Evenson (1994) defined the potential spillover for a biological technology as $S_{ij} = Y_{ij}/Y_{jj}$, where $Y_{ij}$ is the yield in environment $j$ of varieties developed for that environment and $Y_{jj}$ is the yield of the same group of varieties in environment $i$. Byerlee (1997) reported that the extent of the spillover, ie, the size of $S_{ij}$ depends on various factors: agroecological similarity between the originating and receiving region, local food tastes and preferences, factor prices and institutional factors (land tenure and intellectual property rights). He also mentioned that realization of the potential spillover is influenced by other factors such as historical and cultural links between countries, geographical proximity, complexity of the problem and other institutional factors (the research networks and the level of intellectual property rights).

Across-commodity spillover effect occurs when the technology developed has applicability across commodities. For example, a cultural management technique specially developed for sorghum production may also have the potential of improving the efficiency of production of millets and other cereals. Across-commodity spillover has been termed by Evenson (1989) as intercommodity spillover. He mentioned that for some technologies the spillover mechanism would not be confined to a single commodity. Resource-or input-based technology may be relevant to several commodities. Pretechnology science findings may spill over across commodities because they enhance the invention
potential of several commodity technology programs. For example, programs to control insects or correct a soil problem will spill over across commodities. A screening technology developed for sorghum may be equally useful for pearl millet screening. Research on biological control of *Helicoverpa* in chickpea and pigeonpea may be equally applicable in cotton and sorghum.

Price spillover occurs when the technological change for a particular commodity at a specific location increases supply and changes the price of that commodity in other locations through trade. It may also significantly affect the price of a related commodity in the same location. This is particularly relevant for products with low demand elasticity, and/or when the rate of product transformation among commodities is significant (Bantilan and Davis 1991).

Price spillovers can be seen as a case of intersectoral spillover as discussed by Evenson (1989). He elaborated that most private (and public) firms in an economy conduct two types of research programs. The first is directed toward process improvements in the sector itself (usually within the firm). Such research does not have spillover effects on another sector except by way of price. The second type of research is directed to product improvement. Such research can result in real and accounting spillovers because, when product quality changes, it is almost impossible to account for the quality change in terms of the price. When a manufacturer introduces a new machine and sells it at a price that is 10% higher than the price of an existing machine, accounting methods will measure the new machine as providing 10% more real services to the agricultural sector. However, there are at least two reasons why the new machine is likely to be providing 10% more real service. First, the manufacturer will have to provide a real discount to farmers to sell the new machine. Second, competition and expected competition from other manufacturers will lead him to give a real discount to farmers. Such real discounts associated with the introduction of new products from the farm-input supply sector constitute research spillovers to the agricultural sector.

Evenson (1989) also discusses another type of spillover: interfoci spillover. He defines it in the context of research system design, which is characterized by a set of hierarchical research foci. He relates this to most agricultural research programs where investment occurs in three stages: (a) pretechnology science; (b) technology invention and development; and (c) technology development and sub-invention. These stages correspond to specific specialization, which lead to locational specialization. Invention and development of new technology, ie, stage b, is the central objective of NARSs as well as IARCs. It is well-recognized that technology development rests on the twin pillars of science and technology which together define the invention potential of a national program. Almost all national and international research institutions invest in pretechnology science research programs, ie, stage a, to build invention potential. Genome mapping techniques (such as RFLP mapping and polymerase chain reaction) and genome transformation activities at ICRISAT are examples of pretechnology science research which immensely helps in technology generation and development for a group of crops rather than a single one. By enhancing invention potential, pretechnology science research has a spillover effect on programs within the given system as well as on other national and international research programs. Technology developed in one country may enhance the invention potential in another even if it is not directly transferable. Plant varieties, for example, may be valuable as germplasm in the breeding programs of another nation or state. Another example of interfoci spillover is the ongoing genome transformation activity at ICRISAT – which relates to research stage b – which is likely to make an immense contribution to prevention of fungal diseases in sorghum.

Most national research programs, especially those of small countries, concentrate on adaptive development and subinvention, ie, stage c. Typically, they are technologically dependent on
international research institutes, and receive direct and indirect research spillover\textsuperscript{4} from them. For example, Bangladesh has released six chickpea varieties; of these, four were drawn from ICRISAT crosses after screening and adaptive research trials. The other two were also from crosses provided by another international research center. Thus, Evenson’s interfoci research spillover is really an indirect type of across-location spillover.

This chapter discusses the technology spillover potential from enhanced sorghum germplasm and its determinants. Actual/realized spillover from improved sorghum technologies generated by sorghum scientists are also documented.

11.2. Data and Research Methodology

11.2.1. Data

This study used data obtained from three different sources: International Sorghum Varietal and Hybrid Adaptation Trial (ISVHAT), All India Coordinated Sorghum Improvement Project (AICSIP) and NARS survey data obtained through ICRISAT’s Impact Monitoring Survey.

ISVHAT Data

ICRISAT commenced international yield testing of sorghum cultivars in 1976. Several yield trials were distributed by individual breeders until 1988. From 1989 to 1993, the trial was conducted by the Cooperative Cereals Research Network. It contained 26 elite sorghum genotypes and materials from all ICRISAT centers in Asia and Africa. Materials from Egypt, India, Sudan and Syria too were incorporated. Once every two years, the trial was reconstituted with new genotypes. Each year data from 25-30 locations, ranging in latitudes from 20\textdegree S to 43\textdegree N, were obtained. Data on phonology, plant height, grain yield and response to important pests and diseases were collected. (Alagarswamy 1996).

The trial provided scientists from various disciplines an opportunity to collaborate in the systematic evaluation of sorghum cultivars, and to contribute to the identification of cultivars adapted to specific regions in the semi-arid tropics in order to facilitate sustainable sorghum production. The trial’s main objectives were to:

- make available to sorghum scientists the world’s elite breeding lines, varieties and hybrids either for direct use or as parents in crosses within their breeding programs
- provide sorghum scientists an opportunity to assess the performance of their advanced breeding lines and released cultivars over a wide range of climatic, soil, disease and insect conditions
- identify lines with stable resistance to major disease, insects and other stresses
- identify similarities and differences in the effects of test environments on the performance of sorghum cultivars, and to achieve more focused testing
- serve as an information dissemination center on sorghum cultivar performance over a range of environments.

During 1989-92, trials were conducted in 59 locations spanning 26 countries in Asia, Africa and Latin America. The test locations and their physical environments are described in Table 11.1.

\textsuperscript{4} Spillin and spillover refer to the same phenomenon of externality. The terms are used interchangeably depending on whether a research program is receiving or producing the externality.

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Figure 11.2 shows the locations of the trials. The trials comprised of about 25 cultivars common to all the locations (17 varieties and 8 hybrids, including a hybrid and a variety check). The AICSIP contributed 1 hybrid and 2 varieties. ICRISAT-Patancheru’s Cereals Program contributed 6 hybrids and 6 varieties while its regional programs contributed 10 varieties (2 from WASIP, 4 from EARCAL, 2 from the SADC/ICRISAT Program and 2 from LASIP. Table 11.2 summarizes the number of locations to which ISVHAT data were made available between 1989 and 1992. The pedigrees of all the cultivars used in the trials are given in Table 11.3. Besides common cultivars, cooperators were asked to include some of their choice and a local check (a variety or hybrid). The trials were conducted using randomized complete block design with three replications.

**AICSIP Trial Data**

The AICSIP has been conducting adaptive research trials in different states and locations in the country. The data for 1975/76 to 1995/96 were utilized to quantify spillover impacts among different sorghum domains in India. Figures 11.3 and 11.4 show the locations of the trials conducted in India. Details of the locations and year of the trials are given in Table 11.4.

**NARS Survey Data**

A questionnaire (Appendix III) was sent to different sorghum-producing countries in Asia, Africa and Latin America to gather information on the cultivars released, their characteristics (origin, type of cultivar, ie, variety or hybrid), pedigree, year of release, morphological traits (grain color, insect and disease resistance), ecological niches, crop domains for which they were released, commercial success (area cultivated) and reasons for release (grain, forage, dual purpose). It also provided information on the status of sorghum cultivation in the country, ie, area, production and yield in different countries by environment and cultivar. The country’s research capability and infrastructure measured by the number of scientists that support crop improvement in public and private research organizations as well as information on subsequent efforts to produce and promote improved seed (number of seed companies operating in the country) was sought.

**11.2.2. Research Methodology**

Sorghum research in different locations was conducted under eight research domains. A research domain was delineated as a homogeneous ecoregion defined in terms of its soil and climatic conditions and spreading beyond the geographical boundary of a country. For example, the major problem in Sorghum Research Domain (SRD) 2 is grain mold and in SRD 3 stem borer and Striga. The eight sorghum research domains were: wide adaptability (SRD 1), dual purpose with specific adaptability (SRD 2), dual purpose with fodder emphasis (SRD 3), forage sorghum (SRD 4), early sowing postrainy-season sorghum (SRD 5), late sowing postrainy-season sorghum (SRD 6), irrigated sorghum (SRD 7) and extreme altitude sorghum (SRD 8). These have already been discussed in detail in Chapter 1. Here we have estimated the potential technology spillover impact for these eight research domains.

Two types of measurement techniques—subjective and objective—have been used to assess the spillover effects in agriculture (Deb and Bantilan 2001). Subjective estimates are based on value judgments rather than experimental or farm yield/cost data. They are often arrived at through elicitation from experts. Objective estimates, on the other hand, are based on hard data.
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<td>74°.0' E</td>
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<td>20</td>
<td>47</td>
<td>24°.4' N</td>
<td>46°.5' E</td>
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<td>Wad Medani</td>
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<td>48</td>
<td>14°.4' N</td>
<td>33°.3' E</td>
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<td>49</td>
<td>5°.5' S</td>
<td>35°.6' E</td>
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...continued
and evidence reflecting the extent of applicability of a new technology across environments or commodities beyond the research target. Data requirement and methods of analysis for objective estimates vary, depending on the type of spillover to be assessed.

To quantify spillover impacts (ie, estimation of the coefficients of sorghum spillover matrix), an econometric approach based on yield trial data, similar to that of Maredia et al. (1996) was used. The first step was to identify the origin domain and trial (test) domain of sorghum cultivars tested in AIC SIP and ISVHAT trials. The final step was to quantify spillover matrices.

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<td>30°.5' E</td>
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* = Data available.
Source: ISVHAT reports.

Figure 11.2. ISVHAT trial locations, 1989-1992.
Table 11.2. Number of locations to which ISVHAT data was made available, 1989-92.

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<th>Region</th>
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<td>32</td>
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1 EARCAL = East African Regional Cereals and Legumes Program.
2 WASIP = West African Sorghum Improvement Program.
3 SADC = Southern African Development Committee.
4 LASIP = Latin American Sorghum Improvement Program.
5 RAB = Regional Arab Bureau.
Source: ISVHAT reports.
Estimation of Spillover Matrix

Following Maredia et al. (1996), it was assumed that the performance of a variety is a function of environmental variables (location dummy, year dummy) and technology variables (vintage and origin of the variety). Technology variables were included to represent characteristics of varietal technology. The following regression model was used to estimate the spillover matrix.

\[ Y_{htg} = a + b_h \text{LOC}_h + c_t \text{YEAR}_t + v \text{VINT} + w_i \text{ORIG}_i + r \text{MR} + \epsilon_{htg} \]

for \( j = 1,2,..,n \)

where,

- \( j \) is the test domain in which the yield data point is observed
- \( Y_{htg} \) is the observed yield (kg ha\(^{-1}\)) of the \( g \)th entry at the \( h \)th trial location in environment \( j \) in the \( t \)th trial year
- \( \text{LOC}_h \) is a vector of dummy variables equal to 1 if the data point belongs to location \( h \), and 0 otherwise
- \( \text{YEAR}_t \) is a vector of dummy variables equal to 1 if the data point belongs to year \( t \), and 0 otherwise
- \( \text{VINT} \) is a variable to reflect the vintage of a variety approximated by the trial year in which the \( g \)th variety first appeared
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<th>Cultivar</th>
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<th>Trial years</th>
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<td>ICSA 32 × SPL 16 R</td>
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<td>ICSA 11 × MR 913</td>
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Source: ISVHAT reports.
Table 11.4. Multilocalional trials conducted by AICSIP, 1975-95.

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<td>RK Pura (Jammu)</td>
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</tbody>
</table>

* = Data available.
Source: AICSIP reports (various years).
$D_{ORIG_i}$ is a vector of dummy variables equal to 1 if the $g^{th}$ variety belongs to the origin group $i$, and 0 otherwise. 

$MR$ is the inverse Mill's ratio. 

$\varepsilon$ is the error term.

ISVHAT panel data was used to estimate the model. Location and year dummies (DLOC and DYEAR) were included to factor out the site and time effects (such as different levels of management) on the observed trial. To correct probable selection bias related to the correlation between varietal attrition and experimental response (ie, yield) of nonrandomly missing varieties in the trials conducted over a number of years, the variable $MR$ (inverse Mill’s ratio) was included. The model was estimated separately for each sorghum domain; therefore the coefficients for $D_{ORIG_i}$ represent the performance of varieties of different environmental origins in a given sorghum domain relative to the ‘home varieties’. The varietal group originating from the test domain was considered the benchmark variable (ie, the dummy variable $D_{ORIG_i}$ was dropped from the equation for each domain). Therefore, the coefficients of $D_{ORIG_i}$ are the differential yields defined as ($w_i = Y_{ij} - Y_{jj}$). These coefficients were used to estimate $Y_{ij}/Y_{jj}$ to give the elements of the spillover matrix, $C_{ij}$, based on the constant $Y_{jj}$ (approximated by the arithmetic mean) for each domain.

### 11.3. Technology Spillover Potential

#### 11.3.1. Across Sorghum Research Domain Spillover Matrix for the World

Model parameters in Equation (11.1) were estimated using the ordinary least square method from ISVHAT data. Results from the regression analyses (Table 11.5.) indicate that the inclusion of the location dummy variables had a significant positive effect on the $R^2$ of all the seven regression models. Similarly, the year dummy variables for the trial years significantly increased the $R^2$ of the estimated models. The coefficient of the $MR$ variable indicates the relationship between observed yields and the probability of retention in the trials.

The coefficient of origin variables ($w_i$) estimate the yield advantage or disadvantage (kg ha$^{-1}$) of varieties originating in different sorghum domains relative to the test sorghum domain. The zeros on the diagonal indicate that the coefficient of variety group of the same domain origin as the test domain is defined as the ‘benchmark’ and all the other coefficients in that column represent deviations from that value.

The negative values of NARS technology in most of the sorghum research domains (Table 11.5) confirm the hypothesis that varieties developed in a test domain perform better than those developed in other domains. For example, NARS varieties of SRD2 origin on an average yielded 96 kg less in SRD1 (after adjusting for other variables). However, it needs to be mentioned that the values (related to $D_{ORIG_i}$) in most of the cases were not statistically significant. Negative values in a given column result from either both genetic differences among cultivars and a difference in the selective domain at the test versus origin domain, or only from a difference in the genetic properties of the cultivars tested. The latter circumstances could reflect different levels of breeding success and would result in a symmetrical relationship such that $w_{ij} = - w_{ji}$. The abundance of negative values both above and below the diagonal shows that ICRISAT’s sorghum domains reflect true differences in selective environmental properties.

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$^5$ Home varieties are the best performing varieties presently cultivated in the area. In other words, the ‘checks’ used in the yield trails.
The last row shows that ICRISAT cultivars performed well in most sorghum research domains, especially SRD1, SRD2, SRD3 and SRD8.2. For example, ICRISAT cultivars bred at Patancheru enjoyed a yield advantage of 277 kg ha\(^{-1}\) in SRD1, 354 kg ha\(^{-1}\) in SRD3 and 175 kg ha\(^{-1}\) in SRD2. This positive yield advantage indicates their potential to spill over to these test domains. It also indicates the success of ICRISAT’s breeding for wide adaptability. This interpretation is strengthened by data in Table 11.6.

Table 11.6 presents the average yield (kg ha\(^{-1}\)) of sorghum cultivated in ISVHAT trials. The grain yield of ICRISAT-bred cultivars was higher in all the sorghum domains compared to those bred exclusively for those domains, except in the case of SRD7 and SRD8.1. In SRD1, it was 472 kg ha\(^{-1}\) while in SRD2 it was 446 kg ha\(^{-1}\). In SRD3, ICRISAT-bred cultivars had a yield advantage of 256 kg ha\(^{-1}\) while in SRD4 and SRD 8.2 the corresponding figures were 1645 kg ha\(^{-1}\) and 995 kg ha\(^{-1}\). SRD4 is the sorghum domain for forage-type sorghum. Therefore, comparing grain yield is not appropriate. One of the major limitations in ISVHAT is the lack of data on fodder yield. ICRISAT’s programs were not breeding and testing for forage. However, the lower grain yield of NARS-bred cultivars for forage in SRD4 compared to those developed in other sorghum domains suggests that research on forage sorghum was probably successful in developing more stalk-producing cultivars (but with low grain yield). Sorghum cultivars developed for SRD 7 (irrigated environment) and SRD 3 (dual purpose, late maturing) also performed better in SRD 2 (dual purpose, early maturing).
than the local NARS-bred cultivars. This indicates the potential of sorghum cultivars developed for irrigated domain to spill over into rainy season, late maturing and dual-purpose sorghum areas. However, it may be noted here that irrigated-type sorghums may not have an advantage in terms of fodder yield since this was not available in ISVHAT data. The higher grain yield of SRD3 cultivars compared to SRD2 cultivars indicates the high spillover potential between two different maturity groups of dual-purpose sorghum. Again, firm conclusions cannot be drawn without analyzing fodder yield data which is one of the two major objectives—high grain yield and high fodder yield—of sorghum breeding for dual purposes.

The spillover coefficients are presented in Table 11.7 in terms of percentage coefficients based on average yields of the benchmark variables (i.e., $c_{ij} = Y_{ij} / Y_{jj}$). Off-diagonal values of less than one indicate that sorghum cultivars directly introduced from other sorghum domains yielded less than those developed by local breeding programs in the test domain. Similarly, values greater

<table>
<thead>
<tr>
<th>Origin of cultivar</th>
<th>SRD1</th>
<th>SRD2</th>
<th>SRD3</th>
<th>SRD4</th>
<th>SRD7</th>
<th>SRD8.1</th>
<th>SRD8.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRD1</td>
<td>3123</td>
<td>3288</td>
<td>2946</td>
<td>2103</td>
<td>5418</td>
<td>5390</td>
<td>4266</td>
</tr>
<tr>
<td>SRD2</td>
<td>2991</td>
<td>3463</td>
<td>3042</td>
<td>2633</td>
<td>5733</td>
<td>3498</td>
<td>4705</td>
</tr>
<tr>
<td>SRD3</td>
<td>2758</td>
<td>3622</td>
<td>3500</td>
<td>2362</td>
<td>6267</td>
<td>6275</td>
<td>4457</td>
</tr>
<tr>
<td>SRD4</td>
<td>No cultivar</td>
<td>No cultivar</td>
<td>No cultivar</td>
<td>1404</td>
<td>No cultivar</td>
<td>No cultivar</td>
<td>No cultivar</td>
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<tr>
<td>SRD7</td>
<td>2490</td>
<td>3913</td>
<td>2788</td>
<td>1793</td>
<td>7381</td>
<td>No cultivar</td>
<td>No cultivar</td>
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<tr>
<td>SRD8.1</td>
<td>No cultivar</td>
<td>No cultivar</td>
<td>No cultivar</td>
<td>No cultivar</td>
<td>No cultivar</td>
<td>No cultivar</td>
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<tr>
<td>SRD8.2</td>
<td>No cultivar</td>
<td>No cultivar</td>
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<td>No cultivar</td>
<td>No cultivar</td>
<td>No cultivar</td>
<td>No cultivar</td>
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<tr>
<td>ICRISAT-Patancheru</td>
<td>3595</td>
<td>3909</td>
<td>3756</td>
<td>3049</td>
<td>6142</td>
<td>4973</td>
<td>4672</td>
</tr>
</tbody>
</table>

Source: Authors' estimate.

Table 11.7. Estimated spillover matrix for sorghum improvement research at the global Sorghum Research Domain level (computed from ISVHAT trial data, 1989-92).

<table>
<thead>
<tr>
<th>Origin of cultivar</th>
<th>SRD1</th>
<th>SRD2</th>
<th>SRD3</th>
<th>SRD4</th>
<th>SRD7</th>
<th>SRD8.1</th>
<th>SRD8.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRD1</td>
<td>1.00</td>
<td>0.95</td>
<td>0.84</td>
<td>1.50</td>
<td>0.73</td>
<td>0.36</td>
<td>1.16</td>
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<tr>
<td>SRD2</td>
<td>0.96</td>
<td>1.00</td>
<td>0.87</td>
<td>1.88</td>
<td>0.78</td>
<td>0.23</td>
<td>1.28</td>
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<tr>
<td>SRD3</td>
<td>0.88</td>
<td>1.05</td>
<td>1.00</td>
<td>1.68</td>
<td>0.85</td>
<td>0.42</td>
<td>1.21</td>
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<tr>
<td>SRD4</td>
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<td>1.00</td>
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<tr>
<td>SRD7</td>
<td>0.80</td>
<td>1.13</td>
<td>0.80</td>
<td>1.28</td>
<td>1.00</td>
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<tr>
<td>SRD8.1</td>
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<td>1.00</td>
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<td>1.00</td>
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<td>SRD8.2</td>
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<tr>
<td>ICRISAT-Patancheru</td>
<td>1.15</td>
<td>1.13</td>
<td>1.07</td>
<td>2.17</td>
<td>0.83</td>
<td>0.33</td>
<td>1.27</td>
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</table>

Source: Authors' estimate.
than one (as in the case of ICRISAT-Patancheru-bred cultivars) indicate that sorghum cultivars directly introduced from these sources tended to yield more than those developed by local breeding programs in the test domain.

The significant yield advantages shown by varieties developed and evaluated in SRD 7 and SRD 8.1 (implying less direct spillins of cultivars developed for other sorghum domains) can be explained by the fact that sorghum cultivars bred for rainfed environments cannot perform better in irrigated environments. ‘Environmental distance’ plays a role in explaining the significant yield advantage enjoyed by locally-bred cultivars in SRD 7 (irrigated) and SRD 8.1 (high altitude). The poor performance of all the cultivars developed for other sorghum research domains or bred for wide adaptability by ICRISAT-Patancheru in SRD 8.1 (high altitude, ie, China) can be explained by the fact that the climate adaptation patterns are entirely different compared to other domains. Therefore, the best way ICRISAT can assist China’s national program is by providing intermediate products (enhanced germplasm materials) rather than finished ones (varieties/hybrids). This argument is strengthened by the fact that of the 10 hybrids developed in China after 1987, 7 are derived from ICRISAT materials, but after incorporating genes for local adaptation. The implications for ICRISAT are that the focus should be on upstream (strategic) research to develop basic materials and provide NARS with strong research programs. ICRISAT moved in this direction in 1995.

Sorghum cultivars developed for irrigated environments (SRD 7) showed 13% grain yield advantage in SRD 2 (late maturing, dual purpose) but not vice versa. The asymmetry of these two domains explains the asymmetry in the spillover matrix (i.e. \( c_{ij} \neq c_{ji} \)). However, without comparing fodder yield it cannot be said that sorghums bred for irrigated environments (SRD 7) were really performing better in SRD 2. The major objective of dual-purpose sorghum (SRD 2) is to provide high grain and fodder yield, while breeding of irrigated sorghum concentrates on increasing grain yield. Therefore, SRD 7 cultivars may provide higher grain yield but not higher fodder (stalk) yield.

An analysis of the performance of ICRISAT-Patancheru-bred cultivars across sorghum domains using the regression analyses reveals wide adaptability and transferability to different sorghum growing domains. This points to the success of research in reducing G × E interactions and developing widely adaptive cultivars, especially in all types of rainfed cultivation and in low altitude areas, which account for a significant share of the sorghum growing area in developing countries.

These results are based on a spillover analysis at the global sorghum domain level using data from ISVHAT coordinated by ICRISAT and with considerable representation of ICRISAT-bred-cultivars. In order to check if the evidence of high transferability of ICRISAT-bred cultivars is sustained, the model in Equation (11.1) was estimated for India in the country-level environments using AICSIP trial data.

### 11.3.2. Across Sorghum Research Domain Spillover Matrix for India

The AICSIP trial data for 1975-96 was used to estimate the spillover coefficient matrix for sorghum in India. It was computed for each of the eight sorghum domains for ICRISAT-derived-cultivars (IDCs) and NARS-derived cultivars. IDCs are those varieties/hybrids developed through research partnership between ICRISAT and NARS using ICRISAT-derived germplasm or breeding material, while NARS-developed cultivars are cultivars developed solely by NARS.

The results of the regression analyses (Table 11.8) indicate that the inclusion of dummy variables for the year had a significant positive effect on the \( R^2 \) of all the seven regression models.
As mentioned earlier, the coefficient of the MR variable indicates the relationship between observed yields and the probability of retention in the trials.

It may be recalled that the coefficient of origin variables \((w_i)\) estimate the yield advantage or disadvantage \((\text{kg ha}^{-1})\) of varieties originating in different environments relative to the test environment. The zeros on the diagonal indicate that the coefficient of variety group with the same origin and test domains is defined as the ‘benchmark’; and all the other coefficients in that column represent deviations from that value.

The dominance of the positive values of Indian NARS-developed varieties for wide adaptability (SRD1) and dual purpose with specific adaptability (SRD2) to other test domains except irrigated sorghum domain (SRD7) confirms the hypothesis that varieties developed by the Indian NARS in SRD1 and SRD2 perform better than varieties developed in other domains. For example, Table 11.8 shows that NARS varieties of SRD1 origin yielded 320 kg more on an average in SRD2 (after adjusting for other variables). Similarly, NARS varieties of SRD1 have a yield advantage of 305 kg ha\(^{-1}\) in SRD3 and 423 kg ha\(^{-1}\) in SRD6. The implication of this finding is that the Indian NARS was successful in its efforts to generate widely adaptable cultivars.

A few negative values can also be found in the coefficients. For example, the field of cultivars originating from SRD2 and SRD5 is less than the cultivars that originated in SRD1 (the wide adaptability domain). Negative values in a given column result from either both genetic differences among cultivars and/or a difference in the adaptation pattern at the test versus origin domain. The genetic difference could reflect different levels of breeding successes and would result in a symmetrical relationship such that \(w_i = -w_j\). The presence of negative values both above and below the diagonal show that the sorghum domains used for the analysis reflect the true differences in selective environmental properties in India.

The last row in Table 11.8 shows that ICRISAT-derived cultivars perform well in most sorghum domains, especially in SRD1, SRD2, SRD3 and SRD4. For example, the dummy for IDCs indicate that they enjoy a yield advantage of 354 kg ha\(^{-1}\) in SRD1, 418 kg ha\(^{-1}\) in SRD2 and 576 kg ha\(^{-1}\) in SRD3. The positive yield advantage of IDCs is an indication of their potential to spill over to these test domains. It also indicates the success of ICRISAT-Patancheru’s breeding program in developing enhanced materials for wide adaptability. This interpretation is strengthened by Table 11.9.

Table 11.9 presents the average yield (kg ha\(^{-1}\)) of sorghum obtained in AIC SIP trials during 1975-96. The per hectare grain yield of IDCs was higher in all the sorghum domains compared to the cultivars bred for those domains, except in SRD7. In SRD1, yield increase was 166 kg ha\(^{-1}\) while in SRD2 it was 328 kg ha\(^{-1}\). The corresponding figures for SRD5 and SRD6 were 492 kg ha\(^{-1}\) and 252 kg ha\(^{-1}\).

The spillover coefficients are presented in Table 11.10 in terms of percentage coefficients based on average yields of the benchmark variables \((\text{i.e., } c_{ij} = Y_{ij}/Y_{jj})\). Off-diagonal values of less than one indicate that sorghum cultivars directly introduced from other sorghum domains yield less than those developed in the test domain. Similarly, values greater than one (as in the case of IDCs) indicate that sorghum cultivars directly introduced from these sources yield more than those developed in the test domain.

A regression analyses of the performance of IDCs across sorghum domains shows their wide adaptability and transferability to different domains. The environmental specificity and associated selective environmental heterogeneity evident in the comparison of NARS-developed cultivars are minimized when IDCs are compared across different sorghum domains. This indicates the success of the collaboration between ICRISAT and Indian NARS in reducing G × E interactions and developing widely adaptive cultivars in India.
### Table 11.8. Regression results of potential spillover at the Sorghum Research Domain level using AICSIP trial data, 1975-96.

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>SRD1</th>
<th>SRD2</th>
<th>SRD3</th>
<th>SRD4</th>
<th>SRD5</th>
<th>SRD6</th>
<th>SRD7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>2302***</td>
<td>2965***</td>
<td>1472***</td>
<td>2423***</td>
<td>2400***</td>
<td>2388***</td>
<td>2880***</td>
</tr>
<tr>
<td>Dummies for year</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R^2$ change</td>
<td>0.04</td>
<td>0.04</td>
<td>0.27</td>
<td>0.08</td>
<td>0.10</td>
<td>0.04</td>
<td>0.03</td>
</tr>
<tr>
<td>$F$ change</td>
<td>-79.03</td>
<td>-161.13</td>
<td>-5.91</td>
<td>-49.94</td>
<td>-70.56</td>
<td>-127.04</td>
<td>-3.78</td>
</tr>
<tr>
<td>Mill's ratio (MR)</td>
<td>-109475***</td>
<td>-197034***</td>
<td>-79704***</td>
<td>-239804***</td>
<td>-240648***</td>
<td>-345329***</td>
<td>-209760***</td>
</tr>
<tr>
<td>Origin, DORIG1,4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DORIG1</td>
<td>-1032***</td>
<td>305*</td>
<td>27</td>
<td>117</td>
<td>423*</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>DORIG2</td>
<td>-257**</td>
<td>-311</td>
<td>54</td>
<td>1303***</td>
<td>-431*</td>
<td>-90</td>
<td></td>
</tr>
<tr>
<td>DORIG5</td>
<td>4</td>
<td>4</td>
<td>103</td>
<td>466***</td>
<td>-4</td>
<td>-389</td>
<td></td>
</tr>
<tr>
<td>DORIG6</td>
<td>286***</td>
<td>291***</td>
<td>1575</td>
<td>2644</td>
<td>3278</td>
<td>466</td>
<td></td>
</tr>
<tr>
<td>Number of observations</td>
<td>2048</td>
<td>10851</td>
<td>635</td>
<td>1575</td>
<td>2644</td>
<td>3278</td>
<td>466</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.16</td>
<td>0.10</td>
<td>0.11</td>
<td>0.11</td>
<td>0.18</td>
<td>0.21</td>
<td>0.22</td>
</tr>
<tr>
<td>$F$ value</td>
<td>102.71***</td>
<td>230.15***</td>
<td>27.89***</td>
<td>66.75**</td>
<td>116.49***</td>
<td>174.53***</td>
<td>27.34***</td>
</tr>
</tbody>
</table>
1. Estimated coefficient (kg ha$^{-1}$).
2. Change in $R^2$ when a given set of dummy variables is included in the equation that includes all the other variables.
3. Change in the $F$-ratio when a given set of dummy variables is included in the equation that includes all the other variables.
4. Origin groups DORIG1 to DORIG6 represent cultivars developed by national programs for the respective domains. DORIG1 indicates cultivars developed at ICRISAT-Patancheru.

### Table 11.9. Average yield (kg ha$^{-1}$) of sorghum obtained in AICSIP trials, 1975-96.

<table>
<thead>
<tr>
<th>Sorghum Research Domains where cultivars were tested</th>
<th>SRD1</th>
<th>SRD2</th>
<th>SRD3</th>
<th>SRD4</th>
<th>SRD5</th>
<th>SRD6</th>
<th>SRD7</th>
<th>Outside</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRD1</td>
<td>2054</td>
<td>3175</td>
<td>1686</td>
<td>2297</td>
<td>2339</td>
<td>2406</td>
<td>2652</td>
<td>1910</td>
</tr>
<tr>
<td>SRD2</td>
<td>1928</td>
<td>2943</td>
<td>1434</td>
<td>2276</td>
<td>2368</td>
<td>3551</td>
<td>2179</td>
<td>1523</td>
</tr>
<tr>
<td>SRD5</td>
<td>1717</td>
<td>2545</td>
<td>2172</td>
<td>2098</td>
<td>2710</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SRD6</td>
<td>2954</td>
<td>1999</td>
<td>2153</td>
<td>2759</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICRISAT-Patancheru</td>
<td>2220</td>
<td>3271</td>
<td>1960</td>
<td>2392</td>
<td>2664</td>
<td>2405</td>
<td>2402</td>
<td>2028</td>
</tr>
</tbody>
</table>

### Table 11.10. Estimated spillover matrix for sorghum improvement research at the Sorghum Research Domain level (computed from AICSIP trial data, 1975-96).

<table>
<thead>
<tr>
<th>Sorghum Research Domains where cultivars were tested</th>
<th>SRD1</th>
<th>SRD2</th>
<th>SRD3</th>
<th>SRD4</th>
<th>SRD5</th>
<th>SRD6</th>
<th>SRD7</th>
<th>Outside</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRD1</td>
<td>1.00</td>
<td>1.08</td>
<td>1.08</td>
<td>1.12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SRD2</td>
<td>0.94</td>
<td>1.00</td>
<td>1.09</td>
<td>1.65</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SRD5</td>
<td>0.84</td>
<td>0.86</td>
<td>1.00</td>
<td>0.97</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SRD6</td>
<td>1.00</td>
<td>0.92</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICRISAT-derived cultivar</td>
<td>1.08</td>
<td>1.11</td>
<td>1.23</td>
<td>1.12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
11.4. Spillover Impacts

Brennan and Bantilan (1999) quantified the spillover impact of ICRISAT research on breeding programs and agricultural production in Australia. They identified ICRISAT germplasm lines released in Australia and grown by farmers there. In the case of sorghum, ICRISAT’s most significant contribution to Australian agriculture has been the introduction of improved midge-resistant lines combined with desirable white grain and tan-colored plant (ICSV 745 and PM 13654). There are several advanced breeding lines that have incorporated midge resistance and a combination of other useful characteristics from ICRISAT-derived material. As a result, experts from the sorghum industry expect hybrids with midge resistance to be available in the near future, and that the resistance of such material will have a significant economic impact on the industry. Assuming that such resistance is likely to increase yield by 5% in 50% of the crop affected by midge each year, the expected yield gains to Australia are estimated at 2.5%. This translates into a cost reduction of $4.02 ton\(^{-1}\) or an annual cost saving of $4.69 million at current average production levels.

Brennan and Bantilan (1999) also assessed the impact of ICRISAT’s global research on Australia, via an impact on prices. ICRISAT’s global research has increased production and decreased sorghum price. Given finite supply and demand elasticities, ICRISAT’s research is likely to have a downward impact on prices for the predominantly export-oriented sorghum industries in Australia. Thus, Australian industries face lower prices and increase in yield. An economic analysis of those spillover impacts in an economic welfare framework revealed that the overall net effect for Australia was a reduction in benefits gained by producers. Australian sorghum producers will lose more through lower prices than through the benefits they gain from higher yields, resulting in an overall loss of A$ 0.55 million per year. These losses occur because Australian producers are unable to make use of the productivity gains from ICRISAT’s research as much as producers in the rest of the world. Hence, other producers experience greater cost reductions than do Australian producers. On the other hand, Australian consumers of sorghum (ie, primarily the livestock sector) will gain an average of A$1.69 million per year. Overall, the net gain to Australia as a result of ICRISAT’s sorghum research effort averages A$1.14 million per year, or an aggregate of A$27.3 million (in 1996 dollars) over the period to 2022.

Actual spillover benefits have accrued in sorghum-growing countries. Macia, a variety released in Mozambique, was also later released in Botswana, Tanzania and Namibia (Table 11.11). Similarly, S 35 was developed in India and adopted by farmers of Cameroon and Chad. ICSV 111 was developed in India and released in Burkina Faso, Chad and Nigeria. ICSV 1079 BF was developed in Burkina Faso but is now cultivated by farmers in Mali. SPV 475 developed for India is now cultivated in Malawi, Swaziland and Zimbabwe. Seredo was developed for Uganda but also cultivated by farmers of Ethiopia, Kenya and Tanzania.

These examples show that breeders were successful in generating technology with wide adaptability and technology spillover potential; and do not substantiate the ‘location specificity’ argument (at least in terms of yields). Sorghum cultivars originating from the collaborative ICRISAT-NARS international research system have proven to be highly transferable within sorghum domains and across different countries around the world.
11.5. Determinants of Technology Spillover

To identify the factors responsible for technology spillover, the strengths of different NARS in terms of scientific capability measured through the number of scientists and their formal education level was dwelt on. India and China are the two countries with strong research capabilities in Asia (see Chapter 1). They have a large scientific mass (China - 200 scientists and India - 150). Other countries have a limited number of scientists ranging between 3 (Rwanda) and 50 (Ethiopia). The extent of the formal education of sorghum breeders in a country indicates the country’s capability to generate new technology while its number of agronomists, seed technologists, entomologists, pathologists and social scientists reveals its strength in adaptive research. Therefore, it is likely that the larger share of released cultivars from international sources after adaptive trials comes from countries with fewer breeders. On the other hand, countries with a large pool of breeders are expected to release more cultivars from their own crosses. Countries with good research strength are also expected to use large amounts of breeding material from international research centers. This is reflected in the pedigree of their released cultivars. An analysis in Chapter 1 shows that more cultivars are released from ICRISAT-supplied materials in countries with limited research capability than in countries with good research capability.

### Table 11.11. Sorghum germplasm spillovers.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Production system(^1) and country where originally selected</th>
<th>Spillover into</th>
</tr>
</thead>
<tbody>
<tr>
<td>5D x 160</td>
<td>21 Uganda</td>
<td>21 Rwanda; 20, 21 Burundi</td>
</tr>
<tr>
<td>Dinkmash</td>
<td>8 India</td>
<td>19, 20 Ethiopia</td>
</tr>
<tr>
<td>Gambella 1107</td>
<td>20 Ethiopia</td>
<td>20, 21 Burundi</td>
</tr>
<tr>
<td>Ingazi</td>
<td>8 India</td>
<td>19, 20 Kenya</td>
</tr>
<tr>
<td>Macia</td>
<td>20 Mozambique</td>
<td>19 Botswana Tanzania, Namibia</td>
</tr>
<tr>
<td>Melkamash</td>
<td>8 India</td>
<td>20 Ethiopia</td>
</tr>
<tr>
<td>Seredo</td>
<td>21 Uganda</td>
<td>19 Ethiopia; 20, 21 Kenya; 20 Tanzania</td>
</tr>
<tr>
<td>SPV 475</td>
<td>8 India</td>
<td>20 Malawi; Swaziland, Zimbabwe</td>
</tr>
<tr>
<td>SRN 39</td>
<td>8 India; 19 Sudan</td>
<td>20 Kenya; 20 Ethiopia</td>
</tr>
<tr>
<td>Tegemeo</td>
<td>21 Uganda</td>
<td>19, 20 Tanzania; 20 Burundi</td>
</tr>
<tr>
<td>S 35</td>
<td>India</td>
<td>Cameroon, Chad</td>
</tr>
<tr>
<td>CE 151</td>
<td>Senegal</td>
<td>Mauritania</td>
</tr>
<tr>
<td>CE 145-66</td>
<td>Senegal</td>
<td>Mauritania</td>
</tr>
<tr>
<td>Malisor 84-1</td>
<td>Mali</td>
<td>Ivory Coast</td>
</tr>
<tr>
<td>BF 83-3/ 48-2-2</td>
<td>Burkina Faso</td>
<td>Senegal</td>
</tr>
<tr>
<td>IRAT</td>
<td>Niger</td>
<td>Burkina Faso, Chad</td>
</tr>
<tr>
<td>ICSV 111 IN</td>
<td>India</td>
<td>Benin, Ghana, Nigeria</td>
</tr>
<tr>
<td>ICSV 1079 BF</td>
<td>Burkina Faso</td>
<td>Mali</td>
</tr>
<tr>
<td>ICSV 1083 BF</td>
<td>Burkina Faso</td>
<td>Togo</td>
</tr>
<tr>
<td>ICSV 1089 BF</td>
<td>Burkina Faso</td>
<td>Senegal</td>
</tr>
<tr>
<td>ICSV 400</td>
<td>India</td>
<td>Nigeria</td>
</tr>
</tbody>
</table>

\(^1\) Production system 8 (PS 8): tropical, low rainfall, primarily rainfed, postrainy season crops are sorghum/oilseed and includes the Western Deccan Plateau of India; Production system 19 (PS 19): lowland, rainfed, short season (less than 100 days) and suitable for sorghum/millet/rangeland and located in Sahelian Eastern Africa and the margins of the Kalahari Desert; Production system 20 (PS 20): covers semi-arid area, intermediate season (100-125 days), suitable for sorghum/maize/rangeland and located in Eastern Africa and parts of Southern Africa; and Production system 21 (PS 21): intermediate season (125-150 days), suitable for sorghum/maize/finger millet/legumes and located in Eastern and Southern Africa. The agroecological details of each PS are given in the ICRISAT Annual Report, 1993.

11.6. Lessons from Spillover Estimates

Many important results pertaining to technology transfer emerge from the estimation of the spillover matrix at the global and country levels. Research evaluation models have often used the spillover matrix to account for the benefits from research conducted by other research programs in similar and different environments. These estimates have been based solely on subjective guesses and on the assumption of location specificity which implies that the values of the off-diagonal elements in the spillover matrix are less than those of the diagonal elements.

The results of our analysis do not substantiate the ‘location specificity’ argument (at least in terms of yield) when the international research system is considered a source of research spillovers. Sorghum cultivars originating from collaborative IC RISAT-NARS research have proven to be highly transferable among sorghum domains and across different countries around the world. The yield advantage of the international research system (located in SD 1) was as high as 27% in SD 8.2, 15% in SD 1, 13% in SD 2 and 7% in SD 3. It was found that IDCs generally performed better than NARS-derived cultivars. This scenario holds good for sorghum varieties developed for India. In India, the potential for technologies developed by the Indian NARS for SD 1 to spill over to other sorghum domains is high. An analysis also revealed that the extent of technology spillover from finished products is negatively related to the research capability of NARS. The higher the NARS capability, the lower is the possibility of technology spillover from finished products (varieties/hybrids). This calls for separate breeding strategies at IC RISAT, one for a strong NARS and the other for a weak one. While IC RISAT should continue strategic research and develop intermediate products for a strong NARS, it should also engage in productive partnerships with a weak NARS in order to help them develop finished products (varieties, hybrids).

11.7. References


