Assessment of Past Performances and **Lessons Learned**

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To guide program design, we assessed past research, highlighting successes and failures, both to benchmark projected gains and to derive strategic lessons for the future. This required a progress report on research on the mandate crops in the target countries, with a particular focus on the period since 2000. In making this assessment, we have tried to determine what worked, what didn't, under what conditions and why. Successful adoption of agricultural innovations requires not just the right technology, but the right enabling environment in which that technology is embedded (Sumberg 2005). Specifically, it requires the right mix of markets, institutions and policies to create incentives for adoption. We have used this analytical framework of markets, institutions and policies to analyze case studies of high and low adoption and draw strategic lessons that can guide the way forward and help improve the performance of the program.

This section presents an overview of past performance, sourced mainly from evidence generated by the DIIVA project which covers 8 mandate crops for 12 target countries for 2009-2010 (Walker and Alwang 2015). Adoption rates derive from a mix of household surveys and expert opinion. Figures for India are a weighted average (based on area planted) for the most important states where these crops are grown. Gaps in coverage for sorghum and finger millet in ESA were filled from other studies and information from plant breeders. The coverage is reasonably complete, with information for 46 combinations of countries and crops (for details see annex Tables 2 and 3).

Our assessment uses three indicators:

1. The area planted to improved varieties in the 12 target countries[1], which measures the effectiveness of the breeding program over the last 30-40 years;
2. The share of area planted to improved varieties from varieties released between 2000 and 2013, which measures the effectiveness of the breeding program in the last 10-15 years; and
3. The number of official releases between 2000 and 2013, which measures the efficiency of the breeding program in the last 10-15 years.

The Indian states and the countries referred to in Tables 2 and 3 are listed in Annex Table 1.

1. Adoption, or the share planted to improved varieties

Table 1 shows that:

1. The median rate of adoption across the 46 combinations of crops and countries is 34%. In 15 cases (33%), the adoption rate is 50% or above.
2. For cereals, the adoption rate is just below the median (28%), for pulses (pigeonpea, chickpea, cowpea, common beans, and lentil) just above the median (35%) and for oilseeds (groundnut and soybean) well above the median (47%).
3. India has the highest median rate of adoption of improved varieties (67%), followed by ESA (40%) and WCA (20%).

Based on this evidence, we conclude that adoption performance has been strong for India but less strong for SSA, and stronger for oilseeds and pulses than for cereals. Overall, the performance has been creditable,

[1] India (SA), Burkina Faso, Mali, Niger, Nigeria, Senegal (WCA) and Sudan, Tanzania, Ethiopia, Uganda, Kenya, and Malawi (ESA).

especially in view of three major factors working to constrain adoption: (1) a seed delivery system that relies largely on the public sector and farmer-to-farmer exchange; (2) the limited capacity of many national agricultural research and extension systems, particularly in SSA; and (3) competition from other cereal crops, namely rice and wheat in India and maize in SSA. India's performance shows what can be achieved with a strong national research system and when hybrids make it profitable for the private sector to supply seed. This suggests that adoption rates of over 50% and even 70% are possible given the right combination of technology, delivery system and market demand.

Table 1. Area planted (%) to improved varieties, by region and target country, 2010.

Crop	Groundnut	Pigeonpea	Chickpea	Sorghum	Millets		Lentil	Cowpea	Soybean
					Pearl	Finger			
India									
India	54	68	79	53	67				
West and Central Africa									
Burkina Faso	25			3	3			10	
Mali	20			33	31			53	
Nigeria	19			20	25			39	92
Niger	12			15	12			17	
Senegal	47			41	35			27	
Eastern and Southern Africa									
Sudan			100	40					
Tanzania	32	50		30[a]		<1[a]		31	
Ethiopia			19	8b			15		
Uganda	55			40[c]		10[c]		16	97
Kenya	47	50							
Malawi	58	50							100

Sources: SSA: https://www.asti.cgiar.org/diiva; India: Walker and Alwang (2015), Ch. 14; [a] Orr and Muange (2015); [b] Gierend et al. (2014a); [c] Gierend et al. (2014b).

2. The share of area planted to improved varieties with recently released varieties

Performance was also evaluated by comparing the area planted to improved varieties based on their date of release. The effectiveness of recent breeding programs can be evaluated by comparing the share of the area planted to improved varieties that were released between 2000 and 2013 (Table 2). The crop averages are for the target countries or target states in India (Annex Table 1). Altogether, there are 16 observations available for this period, covering 7 crops and 12 countries.

Table 2 shows that:

- The median coverage is 26%, ranging from 0% (soybean in WCA) to 58% (chickpea in ESA). Thus, roughly one quarter of the area planted to improved varieties is occupied by varieties released in the past 10-15 years.
- For cereals, the coverage is below the median (22%) but for legumes (pigeonpea, chickpea, cowpea), the coverage is the same as the median (26%), and for oilseeds (groundnut and soybean) it is well above the median (41%).
- ESA has the highest median coverage (56%), followed by WCA (41%) and India (24%).

Based on this evidence, we conclude that recent performance has been reasonably effective. Not only have breeding programs developed improved varieties that have proved popular with farmers, but seed systems have successfully delivered improved seed to allow these varieties to be adopted on a significant scale. Particularly impressive is the high coverage of improved varieties of pearl millet (50% in India, 46% in WCA), reflecting the success of hybrids; improved varieties of groundnuts in ESA (56%) and WCA (41%); and improved chickpea varieties in ESA (58%). These examples count among ICRISAT's success stories (Table 4).

For some crops and regions, the coverage of more recent improved varieties is relatively low. This includes groundnut (19%), chickpea (26%) and pigeonpea (24%) in India, and sorghum in all three regions (14-22%). The lower coverage in India may reflect the maturity of the breeding programs which make it harder to improve on previously released varieties. The bar is lifted higher and higher. For sorghum, the explanation is less clear, but in SSA it has proved difficult to develop improved varieties which can match local varieties that combine high yield and high fodder.

Table 2. Area planted (%) to improved varieties, by period of release, 2000s.

Crop	India	WCA	ESA
Sorghum	20	14	22
Millets	50	46	Na.
Groundnut	19	41	56
Pigeonpea	24		18
Chickpea	26		58
Cowpea		45	1
Soybean		0	74

Sources: SSA: https://www.asti.cgiar.org/diiva; India: Walker and Alwang (2015), Ch. 14.

3. The number of official varieties released since 2000

Our third measure of past performance is the number of improved varieties that were officially released between 2000 and 2013 (Table 3). The crop averages are for the target countries or states shown in Appendix Table 1. Altogether there are 16 observations available for this period, covering 7 crops and 12 countries.

Table 3 shows that:

- The median number of releases was 26, or approximately 2 per year. The highest number of releases was for groundnut in India (76) and the lowest was for soybean in WCA (0). For soybean in WCA (Nigeria), there were no releases during this period.
- The highest number of releases (combined across the three regions) were for sorghum and millets (128 and 127, respectively), followed by groundnut (116) and chickpea (85). The lowest number of releases were for cowpea (15) and soybean (7).
- The highest median number of releases was in India (63), followed by WCA (23) and ESA (20).

Table 3. Number of varieties released in target countries, 2000-2013.

Crop	India	WCA	ESA	Total
Sorghum	58	36	34	128
Millets	63	38	26	127
Groundnut	76	23	17	116
Pigeonpea	41		22	63
Chickpea	72		13	85
Cowpea		15		15
Soybean		0	7	7
Total	310	112	119	541

Sources: SSA: https://www.asti.cgiar.org/diiva; India: Walker and Alwang (2015), Ch. 14. Pers comm. NVPR Ganga Rao, A. Singbo, H. Ojulong, D. Kumar Charyulu.

The correlation between the number of varieties released in the 2000s and the share of the area planted to improved varieties covered by these varieties is weak and negative (Pearson's r = -0.453, sig.-level .090). The highest number of releases was for groundnut in India (76) but they occupied only 19% of the area planted to improved varieties (Table 2). Similarly, India released 41 improved varieties of pigeonpea in the same period but they occupied only 24% of the area planted to improved varieties (Table 2). By contrast, the 15 varieties of cowpea released in WCA occupied 45% of the area planted to improved varieties of the crop.

This evidence suggests that breeding programs continue to produce a significant number of improved varieties, particularly for cereals. However, for some crops matching the success of earlier varieties is becoming harder to achieve. Hybrids offer one solution. However, for some crops like cowpea, the solution has been to breed for fodder as well as grain yield. Similarly, for pigeonpea and sorghum, the solution may be to focus on breeding crops for multiple uses (such as fodder and firewood) rather than just for grain.

4. Explaining high and low adoption

1. Interventions resulting in high adoption

Performance can also be evaluated through *ex post* financial analysis of specific interventions. ICRISAT recently conducted such an analysis for 10 interventions (Winter-Nelson and Mazvimavi 2014), using an economic surplus approach, implemented through the Dynamic Research EvaluAtion for Management (DREAM) model. Reported benefits are an estimate of the benefits to adopters of the new technology, ignoring spillover effects through which producers and consumers in other areas may have been affected by the technology. These benefits can be substantial. For the target countries in Phase 1 of the CGIAR Research Program, the potential spillover benefits from improved groundnuts increased the total benefits by a factor of five (Mausch et al. 2013).

Results for 10 interventions are reported in Table 4. The analysis gave estimates of internal rates of return (IRR) ranging from 17% to 70%. The return on investment (ROI) values ranged from US$9 to over US$100 per dollar invested. The average ROI across the projects for which *ex post* analysis was completed is US$43.02 per dollar invested. The corresponding IRR is 41.46%. Each of these values is a weighted average with weights based on the share of total benefits attributed to each project. Higher returns on investment were observed for technologies that had either had long periods under adoption, such as wilt-resistant pigeonpea and drought-tolerant groundnut (Malawi), or had been adopted over larger scales. Due to its scale of application and its long period of use, wilt- resistant pigeonpea has generated an NPV (US$466 million) that dwarfs the other initiatives analyzed here. However, an ex ante analysis for the period 2011-2020 of the economic returns to improved varieties of cowpea in Nigeria suggests potential benefits of a similar magnitude (NPV = US$489 million) (IITA 2016).

ICRISAT has conducted comprehensive impact assessments for some of these interventions. Microdosing (fertilizer adoption) doubled adopters' output of cereals in Zimbabwe (Winter-Nelson et al. 2016). However in Niger, millet yields with microdosing were the same as for other methods of fertilizer application (Liverpool-Tasie et al. in press). Adopters of pearl millet hybrids in India reported yield increases of 18% for grain and 14% for fodder in the 2000s (Charyulu et al. 2014). By contrast, impact assessment of improved pigeonpea in northern Tanzania found no significant yield gains because of yield variability under farmers' field conditions (Dalton and Regier 2013). A meta-analysis of watershed management in India showed a mean benefit-cost ratio of 2 and IRR of 27%, with rural incomes enhanced by 58%, agricultural productivity increased by 35% and additional environmental and social benefits (Wani et al. 2008).

Table 4. Interventions resulting in high adoption, ICRISAT, 1983-2013.					
Intervention	**Time period**	**Maximum adoption**	**Net Present Value of benefits (million US$)**	**Return on investment (US$)**	**Internal Rate of Return (%)**
Drought-tolerant groundnut, Malawi	1983-2013	40%	35	102	40
Drought-tolerant groundnut, Nigeria	1996-2013	30%	76	50	42
Drought-tolerant groundnut, Anantapur, India	1991-2020	35%	55	57	23
Early pearl millet hybrid, NW India	1999-2013	27%	155	44	20
Pigeonpea, northern Tanzania	1993-2022	56%	5	9	17
Fusarium wilt-resistant pigeonpea, India	1975-2013	60%	466	106	32
Fertilizer microdosing, Zimbabwe	1999-2013	30%	27	11	36
Fertilizer microdosing, Niger	1994-2013	27%	120	41	38
Pearl millet hybrids, India	2000-2013	26%	124	61	70
Sorghum hybrids, India	2000-2013	40%	73	48	65
Average				70	36

Source: Winter-Nelson and Mazvimavi (2014).

2. Case studies of high and low adoption

High adoption is often attributed to a winning combination of markets, institutions and policies. They are particularly relevant for this program where the mandate crops have little attraction for the private sector, and receive less public investment because they are seen as minor or a 'poor man's' crops. We assessed the relevance of this analytical framework using four case studies – two of high adoption and two of low adoption.

Case study # 1. High adoption: Hybrid pearl millet in India

Since the 1960s, the area planted to pearl millet in India has contracted but yields have tripled, and production has doubled. Almost 60% of the area under pearl millet is now planted to improved varieties. This remarkable growth is due to the widespread adoption of hybrid varieties since the late 1980s. The successful introduction of this new technology is attributed to the following combination of factors:

Markets: While the all-India demand for pearl millet as a food has fallen with urbanization, higher incomes, and changing food habits (Charyulu et al. 2014), there exists a strong market demand for it in semi-arid states like Rajasthan and Gujarat, and pearl millet continues to be an important staple for the poor. About 46% of pearl millet in urban India is consumed by low income consumers. More than half of pearl millet production now finds its way to alternative uses, such as poultry feed and raw material in the alcohol and food processing industries

(Bhagavatula et al. 2013). There is also a growing market for pearl millet straw in urban areas close to growing centers to meet the increasing demand from urban and peri-urban dairies. Chopped pearl millet straw is commonly traded in urban markets due to its transportability and ease of consumption.

Institutions: Hybrid pearl millet was the result of a novel partnership – the Hybrid Parents Research Consortium (HPRC) – which saw the sharing of germplasm between ICRISAT, the private sector, and the Indian national research system. Private sector participation was stimulated by the large size of the market, the fact that farmers were already used to regular seed replacements, and the ongoing demand for new and disease-resistant products. ICRISAT breeders targeted a key adoption constraint – downy mildew – that led to the development of two hybrid varieties (ICMH 451 and 501) that were resistant to this disease. Private breeding companies then used ICMH 451 and 501 to develop a wide range of hybrids. In 1981, MBH-110 (pearl millet) was the first private hybrid of any crop to be officially released by the Government of India. Extra-early drought-resistant varieties were also developed. By 2007, over 80% of the seed for improved varieties originated in the private sector. More than 50 private firms market approximately 75 hybrids of pearl millet. The partnership strengthened with the formation of a Hybrid Parents' Research Consortium in 2000. In 2010, 25 seed companies were members of the consortium. Between 2000 and 2010, private companies developed 103 hybrids, of which 62 (60%) used ICRISAT-bred materials. About 60 (80%) of the 75 widely-adopted hybrid pearl millet varieties are based on ICRISAT-bred hybrid parents (Charyulu et al. 2014).

Policies: Favorable policies included de-regulation, a new seed policy and the introduction of truthfully labelled seed which cleared the way for privatization of the seed trade (Charyulu et al. 2014. Since 2013, coarse grains were included in the public food distribution system. Theoretically, each eligible consumer is now entitled to 5 kg/month of foodgrains at a price of INR 1/kg for millets and sorghum. However, it is too soon to say whether this has stimulated demand for millets. The ability of the government to procure coarse cereals at market or support prices and supply them to the consumers at INR 1/kg appears to be difficult (Charyulu et al. 2014.

Conclusion**:** Success was achieved in this instance by enlisting the private sector in the development and marketing of hybrid varieties to fit a range of agroecosystems, and meeting the growing market demand for poultry feed.

Case study # 2. High adoption: Improved cowpea in Nigeria

Nigeria is the world's largest producer and consumer of cowpea, with 45% of global and 55% of Africa's production. About 39% of the area planted is occupied by improved varieties. Since the early 1990s, the breeding program has focused on the development of improved dual-purpose cowpea (IDPC). Two dual-purpose varieties (IT90K-277-2 and IT89KD-288) are the most popular in Nigeria, and together account for 44% of the area planted to improved varieties (Walker and Alwang 2015).

Markets: Farmers sell both cowpea grain and fodder. Demand for grain exceeds supply and Nigeria imports about 25% of its requirements (Langyintuo et al. 2003). However, demand for fodder has to be met from domestic supply. Dual-purpose cowpea allows farmers to combine both higher grain and fodder production in the same variety, rather than growing separate varieties as they did before. Farmers report that higher income from sale of grain and fodder is the main incentive for the adoption of IDPC. Adoption is certainly higher where farmers are closest to markets. However, the highest adopters are poorer households who have more goats/family members, suggesting that fodder to feed household livestock is a key incentive (Kristjanson et al. 2005). Income from higher yields also benefits women, who process the grain into cakes for sale and sell it for seed the following season, using the additional income as savings for their daughters (Tipilda et al. 2008).

Institutions: Adoption was accelerated through an innovative partnership. A new seed delivery system, involving IITA, the national research program, and local government, was developed to diffuse IDPC varieties from farmer to farmer. Activities included the multiplication of breeder and foundation seed, training farmers in seed production techniques and catalyzing farmer-to-farmer seed diffusion for strategic seed reserve development at the household level, and forming seed growers associations to establish strategic seed reserves at the state level. Adoption of an improved package of practices for cowpea was promoted through farmer field schools (Alene and Manyong 2006).

Policies: Nigeria enjoys free trade in cowpea thanks to its membership in the Economic Community of West African States (ECOWAS), which includes Niger, its main source of cowpea imports. Decentralization and the power given to state governments in Nigeria's federal system meant that the local government was closely involved in the promotion of IDPC varieties, while flexible seed policies allowed farmer organizations to grow and sell certified seed.

Conclusion: Success was the result of cleverly combining two equally-valued traits into a single product that met existing market demands. Adoption rates are still below those in neighboring Ghana (82%) and Cameroon (71%). The problem is one of scale: the area planted to cowpea in Nigeria is 14 times greater than that of Ghana and Cameroon combined. Raising adoption rates in Nigeria above 39% will require a huge effort to improve farmers' access to seed, and the lack of private sector involvement means that this can only be achieved by scaling-out institutional changes that promote informal farmer-to-farmer exchange.

Case study # 3. Low adoption: Improved pigeonpea in Malawi

Malawi is the third biggest producer of pigeonpea in ESA, after Tanzania and Mozambique. By 2016, 7 improved varieties had been officially released in Malawi; yet the share planted to improved varieties was below 10% (Simtowe et al. 2013). By contrast, in northern Tanzania, 50% of the area planted to pigeonpea is occupied by improved varieties, 31% by the variety ICEAP 00040. In Malawi, 20 years after its release, the same variety occupies just 9%.

Markets**:** Market prospects are bright. India faces a growing trade deficit in pigeonpea. This presents an opportunity, since the Malawian crop reaches Mumbai before the harvest in India. Exports to India consist of whole grain, but Malawi pigeonpea is also processed into *tur dhal.* To meet the needs of this market, ICRISAT developed Kachangu (ICEAP 00040) and Mwaiwathualimi (ICEAP 00557) with traits liked by Indian consumers (large, round, cream coloured grain) and by processors, since they are easy to dehull.

Institutions: One explanation for low adoption is the absence of an effective seed delivery system. Pigeonpea seed can be recycled for 3 years without loss of vigor, which makes it unattractive for private seed companies. So the delivery of improved seed is left to the public sector. Yet this argument cannot explain the popularity of Mthawajuni, an unknown variety that has spread from farmer-to-farmer over the last 10 years and now occupies 80% of the area planted to pigeonpea in Malawi. Unlike Kachangu or Mwaiwathualimi, this variety has none of the market traits valued by Indian consumers, yet it has been widely adopted by Malawian farmers.

Policies**:** Pigeonpea grain is traded freely and there has never been an export ban. The government of India protects the domestic processing of *tur dhal.* Consequently, exports go to the Indian diaspora in the UK and the USA, not to India (Lo Monaco 2003). In 2015, Indian Prime Minister Narendra Modi committed his government to buy whatever pigeonpea Malawi produced (without specifying the price). The government of India wants to guarantee a market for African exporters in order to discourage Indian companies from speculating in stocks and to protect the Indian consumer. Moreover, Malawi's exports must travel 400 km by rail to Nacala, which reduces its competitive advantage over countries with their own ports, like Tanzania and Mozambique.

Conclusion**:** The low adoption of improved varieties in Malawi may reflect the importance of non-market traits. Early- maturing pigeonpea provides food security for the household. This helps explain the popularity of Mthawajuni over improved varieties like ICEAP 00040, which takes longer to mature. Similarly, pigeonpea stems are widely used for firewood and constitute 34% of the grain's value (Orr et al. 2014). Women, who manage the crop in Malawi, place a high value on these traits (Orr et al. 2014). Prioritizing market traits for crops with multiple uses may not be the most effective strategy for high adoption.

Case study # 4. Low adoption: Conservation agriculture in Zimbabwe

Conservation agriculture (CA) is widely viewed as a way to improve the sustainability, profitability and resilience of smallholder agriculture in SSA. CA is based on the three principles of minimum or no mechanical soil disturbance, permanent organic soil cover through a growing crop or mulch residues and diversified crop rotations (Giller et al. 2009). The specific components of the CA system vary according to location (Corbeels et al. 2014). One component – microdosing, or the spot application of small amounts of inorganic fertilizer – has proved popular and is counted among ICRISAT's success stories (Table 4). Despite its promotion for over two decades, adoption of the CA 'package' has been limited. The share of cropland under CA in Zambia, Kenya and Zimbabwe is less than 1% (Corbeels et al. 2014). ICRISAT and its partners have promoted CA in Zimbabwe since the mid-1990s, and this experience provides useful insights into the role of markets, institutions and policies in explaining low adoption.

***Markets*:** Market conditions are often not in place for the adoption of CA (Corbeels et al. 2014). CA requires functioning input markets for seed, fertilizer, herbicides and planters, which are often lacking. Adoption of legumes in rotation or as intercrops also requires output markets. Without a market for the grain, farmers tend to grow grain legumes only on a limited share of their land (Giller et al. 2009). Market conditions for CA scored poorly in Zimbabwe, reflecting its fragile economy (Corbeels et al. 2014). Most CA projects create their own input and output markets, providing adopters with technical and financial support, but once this stops the majority of farmers revert to their former crop management practices. In Zimbabwe, CA was promoted by an NGO as part a drought relief program, but adoption declined after 2009 with the end of the program (Pedzisa et al. 2015).

***Institutions*:** Contrary to expectation, the adoption of CA was not constrained by a shortage of labor, which is required for making basins and weeding. Smaller families solved this problem through an institutional innovation: pooling their labour in CA labor clubs (Pedziza et al. 2015). One institution hindering the adoption of mulching is the custom of free grazing after harvest: farmers who wanted to use crop residues as mulch would need to mulch their fields (Giller et al. 2009).

***Policies*:** The policy environment has been favorable, since CA has attracted widespread support from national governments, aid agencies, and it features prominently in strategic plans for the agricultural sector in ESA, including Zimbabwe (Corbeels et al. 2014).

***Conclusions*:** The primary reason for low adoption is the variable yield increases from CA, and not immediate (Giller et al. 2009). Moreover, because of trade-offs in the use of labor and crop residues, increased yields may not result in higher incomes at the household level. In the mixed crop-livestock system in semi-arid Zimbabwe, using crop residues to feed livestock – which produce traction, meat, milk, and manure as well as being a source of ready cash – give greater benefits than using them for mulch. A recent review concluded that CA was potentially beneficial for some types of farmer and farming systems in SSA but 'under present circumstances CA is inappropriate for the vast majority of resource-constrained smallholder farmers' (Giller et al. 2009).

5. Lessons learned

Some strategic lessons emerge from this assessment of performance. These are combined with lessons from a previous analysis of 20 ICRISAT 'success stories' with product lines related to specific user groups (Orr and Mausch 2014).

1. Current adoption rates provide a benchmark for the program. On average, improved varieties cover about one-third of the area planted to mandate crops in SSA and about two-thirds in India. This level of

adoption has taken 30-40 years of research and development. These figures should serve as a reality check on the change in adoption and impacts expected from the program.

2. Rates of adoption show large differences between regions. In particular, the average area planted to improved varieties in WCA (20%) is considerably lower than in ESA (40%). The program needs to carefully identify and address the reasons for this difference.
3. Access to improved seed is better than commonly known. About two-fifths of the area planted to improved varieties is occupied by varieties released since 2000. This suggests that in some locations seed systems have performed well and that models of seed delivery exist that might be replicable elsewhere. The program should learn from these experiences and test their replicability.
4. Adoption of improved varieties is accelerating for some crops. Adoption of recently released varieties has been rapid for hybrid millets in India and WCA, and for groundnut, chickpea and pigeonpea in WCA and ESA. Rapid adoption of these crops in target countries suggests that significant spillover benefits exist for non-target countries. The program should plan to ensure that these benefits are realized.
5. The pipeline for plant breeding programs is strong. Since 2000, the three regions have released a total of 541 improved varieties of the mandate crops, a median of 26 per crop. However, for sorghum and groundnut in India, the high number of releases is not reflected in higher adoption. The reasons for this should be identified and addressed by the program.
6. Research and development for the semi-arid tropics can give high returns. A selection of 10 ICRISAT interventions gave an average return of US$70 for every dollar invested. These winning products each clearly addressed a key yield constraint, like drought, disease, or low soil fertility. They did not address higher-order goals like resilience or profitability. The program's new product lines need to be equally clear about which specific production constraint they are designed to address.
7. The performance of new technology for crop management has been mixed. Clearly, the full package of Conservation Agriculture has gotten nowhere, but the fertilizer component has been successful. Most farmers in SSA who adopt microdosing are using fertilizer for the first time, so it is simply the adoption of fertilizer. Given widespread low soil fertility, the impact of microdosing on yields is visible and immediate; which explains why it is so popular. Since improved varieties are fertilizer-responsive, crop management in the program needs to focus on increasing the adoption of fertilizer adoption and optimizing the efficiency of fertilizer use among smallholders with limited cash resources.
8. The Markets-Institutions-Policy rubric is useful because these preconditions can make or break a new technology. Indeed, it is hard to imagine high adoption without at least some combination of these elements, if not all three. Success stories like pearl millet in India and cowpea in Nigeria show they have played an important role in achieving high adoption. However, while they are necessary for high adoption, they are not sufficient. Case studies of low adoption like improved pigeonpea in Malawi and conservation agriculture in Zimbabwe reinforce the importance of having the right product. Focusing on markets, institutions and policies without the right product will not result in high adoption.
9. ICRISAT's 10 most successful product lines all have clearly identified end uses. The market is one end use. But some products have multiple end uses, including sale, home-consumption, or byproducts. The high adoption of dual-purpose cowpea in Nigeria shows the benefits of breeding for both grain and fodder, while the low adoption of improved pigeonpea in Malawi shows the danger of prioritizing market traits over earliness and fuelwood. The program should identify the end uses for each product line to ensure that they have the required traits.
10. Identifying end uses requires socioeconomic research to segment the 'market' or the spectrum of end uses. Specific product lines are then targeted at priority segments of that market. Linking product lines to end uses is easier than linking product lines to generic user groups (such as 'commercial' or 'subsistence' farmers). Developing a clear quantitative picture of different end uses at the national and regional levels should be a priority for socioeconomic research in the program.

Specific lessons that have been incorporated in breeding programs

In addition, many lessons have already been incorporated in breeding programs, resulting in adjustments to breeding objectives. These include:

1. *Increasing adaptability by exploiting traits from local varieties*. In Mali and Burkina Faso, hybrid parents from Guinea race sorghum hybrids were developed directly from local varieties in order to incorporate photoperiod sensitivity, but also grain quality and yield stability (vom Brocke et al. 2010, Rattunde et al. 2013). All new breeding populations of pearl millet in WCA were derived from local germplasm. Photoperiod sensitivity allows late planting in dry years, giving farmers greater flexibility in coping with drought.
2. *Participatory plant breeding that incorporates farmer preferences early in the breeding program*. For instance, much of the development of breeding material in early generations (F_3 and F_4) for sorghum in Mali and Burkina Faso (vom Brocke et al. 2010) and millet are done in collaboration with farmers to ensure that improved varieties fit within the farming systems and the conditions on farmers' fields, specifically high and low P (Leiser et al. 2012).
3. *Dual-purpose crops that integrate crops and livestock*. The cowpea program in Nigeria recognized the importance of cowpea fodder and developed varieties that produced both high grain and fodder yield (Kristjanson et al. 2005). ICRISAT has incorporated stover quality into its breeding program for sorghum and pearl millet in India.
4. *Earliness as a strategy for coping with drought and improving household food security*. Improved varieties of pigeonpea in ESA were tailored to match the phenology of the crop with specific agroecosystems based on day length and temperature (Silim et al. 2006). This ensures maturity before the crop is exposed to drought, and shortens the hunger period.
5. *Gender-responsive plant breeding has resulted in inclusion of women in PVS and gender-disaggregation of trait preferences* (eg. vom Brocke et al. 2010). Gendered trait preferences reflect gender roles, with men and women giving higher priority to traits that are important for their specific roles in production, processing, and marketing (Christinck et al. 2017). Since gender roles vary by crop and country, so do gendered trait preferences in each breeding program.

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Annex

Annex Table 1. Countries/states included for each crop.			
	India	**WCA**	**ESA**
Sorghum	Andhra Pradesh, Maharashtra, Karnataka, Madhya Pradesh, Rajasthan	Nigeria, Senegal, Mali	Ethiopia, Sudan, Kenya, Tanzania
Millets	Rajasthan, Maharashtra, Gujarat, Uttar Pradesh, Haryana	Burkina Faso, Nigeria, Niger, Mali	Sudan, Uganda, Tanzania
Groundnut	Maharashtra, Gujarat, Tamil Nadu, Rajasthan, Karnataka	Burkina Faso, Nigeria, Mali, Senegal	Malawi, Tanzania, Uganda
Pigeonpea	Uttar Pradesh, Tamil Nadu, Madhya Pradesh, Andhra Pradesh, Maharashtra		Kenya, Tanzania, Malawi,
Chickpea	Andhra Pradesh, Karnataka, Uttar Pradesh, Madhya Pradesh, Rajasthan		Ethiopia, Sudan
Cowpea		Burkina Faso, Nigeria, Mali, Niger	
Soybean		Nigeria	Malawi, Uganda

Sources: SSA: https://www.asti.cgiar.org/diiva; India: Walker and Alwang (eds.) (2015), Ch. 14.

Annex Table 2. Area planted (%) to improved varieties, by period of release, 1960-2010.			
Sorghum	**India**	**WCA**	**ESA**
1970s	6	8	28
1980s	9	8	
1990s	30	61	50
2000s	40	14	22
Unknown	16		
Millets	**India**	**WCA**	**ESA**
1970s		13	
1980s	2	25	Na.
1990s	10	16	
2000s	50	46	
Unknown	39	1	
Groundnut	**India**	**WCA**	**ESA**
1960s	1	11	
1970s	7	16	
1980s	14	11	
1990s	44	10	33
2000s	19	41	56
Unknown	15	10	11
Pigeonpea	**India**	**WCA**	**ESA**
1970s	1		
1980s	3		35
1990s	40		7
2000s	24		40
Unknown	31		18
Chickpea	**India**	**WCA**	**ESA**
1970s	13		
1980s	2		2
1990s	22		28
2000s	26		58
Unknown	36		13
Cowpea	**India**	**WCA**	**ESA**
1970s		7	Na.
1980s		23	
1990s		22	
2000s		45	
Unknown		3	
Soybean	**India**	**WCA**	**ESA**
1970s			
1980s		15	4
1990s		85	23
2000s			74
Unknown			

Sources: SSA: https://www.asti.cgiar.org/diiva; India: Walker and Alwang (eds) (2015), Ch. 14.

Annex Table 3. Number of varieties released in target countries, by period.			
Sorghum	**India**	**WCA**	**ESA**
1960s	13		2
1970s	48	19	10
1980s	67	31	4
1990s	71	51	16
2000s	58	36	34
Unknown		9	
Total	257	146	66
Millets	**India**	**WCA**	**ESA**
1960s	6	1	3
1970s	24	7	2
1980s	37	46	3
1990s	53	29	6
2000s	69	38	26
Unknown		1	
Total	189	122	40
Groundnut	**India**	**WCA**	**ESA**
1960s	13	7	1
1970s	25	19	0
1980s	35	17	2
1990s	44	12	2
2000s	76	23	17
Unknown		1	
Total	193	79	22
Pigeonpea	**India**	**WCA**	**ESA**
1970s	35		
1980s	31		3
1990s	37		2
2000s	41		22
Total	144		27
Chickpea	**India**	**WCA**	**ESA**
1970s	29		3
1980s	48		2
1990s	36		9
2000s	72		13
Total	185		27
Cowpea	**India**	**WCA**	**ESA**
1960s		3	
1970s		9	
1980s		14	3
1990s		20	
2000s		15	1
Unknown		6	
Total		67	4
Soybean	**India**	**WCA**	**ESA**
1970s			
1980s		3	5
1990s		6	6
2000s			7
Total		9	18

Sources: SSA: https://www.asti.cgiar.org/diiva; India: Walker and Alwang (2015), Ch. 14. Pers comm. NVPR Ganga Rao, A. Singbo, H. Ojulong, D. Kumara Charyulu.