Priority Setting, Product Lines and Prospective Technologies: **Implications from Phase I for a Consolidated Grain Legumes and Dryland Cereals CRP for Phase II**

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Priority Setting, Product Lines and Prospective Technologies: Implications from Phase I for a Consolidated Grain Legumes and Dryland Cereals CRP for Phase II[1]

In moving to Phase II, the Dryland Cereals, Grain Legumes, and Dryland Systems multicenter CGIAR Research Programs (CRPs) are to be consolidated into a Grain Legumes and Dryland Cereals CRP. This report assesses the substance of priority setting in Phase I with an objective of drawing out implications for Phase II.[2] It responds to the felt need to strengthen priority setting in Phase 2 (ISPC 2016).

Product lines were the organizing construct for delineating the research portfolio for the Phase I Dryland Cereals and Grain Legume CRPs. Each product line is composed of one or more easily identifiable prospective technology that receives the lion's share of the attention in this report. To be viable, prospective technologies should satisfy thresholds related to a critical mass in investment, characteristics of international public goods, comparative advantage in their supply, and, most importantly, demand for their application. Without clarity in the definition of prospective technologies, institutional attribution in *ex-post* impact assessment cannot be established. I argue that prospective technologies are the appropriate unit for priority setting in Phase II.

Priority setting is writ large in this report: several dimensions of research resource allocation are treated. These include focus crops, demand, alternative suppliers, cropwise dryland character, target countries, existing product lines, their allied prospective technologies, and emerging new or consolidated opportunities for Phase II. Many studies were carried out in Phase I that touched upon aspects of priority setting. These are briefly highlighted for their importance and relevance in each of the above dimensions.

Priority setting is discussed from the perspective of a general agriculturalist. It has a decided historical flavor. What has and has not worked in the past and why is of paramount interest, because reinventing the wheel is unlikely to work in the future.

The treatment is not as comprehensive as it could be. Of the four CG Centers participating in the three Dryland Cereals, Grain Legumes, and Dryland Systems CRPs in Phase I, priority-setting investigations from ICRISAT are the only ones that are thoroughly surveyed. This emphasis is reasonable because ICRISAT-mandated commodities contribute about 3/4 of the value of production in the amalgamated Phase II crop portfolio in the target countries; the semi-arid tropics account for about 65% of total dryland cultivated area in the same countries.

The important issue of complementaries in R&D across CG Centers participating in a Dryland CRP is not addressed directly. The desirability and the extent of the whole being greater than the sum of the parts was treated in depth in the Phase I reviews of the 16 CRPs.

What a greater investment in social science, in agroecological awareness, and in systems orientation would bring to the research portfolio, in general, and prospective technologies, in particular, is addressed later in the report. The main finding emerging from that discussion is: not much. Substantial benefits are not discernible to this observer. Restructuring the research portfolio to accommodate these emphases is unlikely to compensate for transactions costs, to improve transparency, or lead to the identification of other prospective technologies with international public goods character that compete with the current set in a time of budgetary tightening.

[1] I thank Shoba Sivasankar, the director of the DCL CRP, for her encouragement in directing this work and for showing extreme patience with the author. I am also grateful to Kai Mausch for assembling ICRISAT-related priority setting research in Phase I and for providing summaries of that work. Arega Alene was instrumental in commenting on and presenting the way forward for priority setting for Phase II in the October workshop.

[2] Thinking about an appropriate process for priority setting in Phase II was outlined in a brief memo and later in a powerpoint presentation at the October Results workshop for participants in the Dryland Cereals and Grain Legumes CRPs (Alene et al. 2016).

Priority Setting in Phase I

Most of the 16 CRPs did not engage in a rigorous priority setting exercise in structuring or in modifying their research portfolios in Phase I which was marked by the aggregation of 50 to as many as 150 bilateral projects into major component thematic areas in each CRP. Explicit priority setting among the major thematic components or flagships or among well-defined activities within each flagship was not conducted. Indeed, the definition of the flagship areas does not vary that much across the crop-based CRPs. In general, the flagships are defined chronologically and sequentially in the R&D process beginning with priority setting, genomics and pre-breeding, varietal development and moving on to crop and postharvest management, development, and impact. At the flagship level, everything is interdependent; it is too aggregate a setting to conduct priority setting on.

The Roots, Tubers, and Bananas (RTB) CRP was the most notable exception. It carried out an exhaustive priority setting analysis for 30 of the most important problematic areas and technological solutions representative of its research agenda. Its stakeholder-oriented, participatory approach fostered support for research and also generated some surprising results that are potentially informative for research resource allocation. For example, the value of work on sweet potato viruses was substantially higher than expected relative to other more publicized research areas like biofortification. The evaluation of the RTB CRP commended the program on its comprehensive work in priority setting, but noted that there was little if any transparent evidence that the results had influenced decision making on research resource allocation in Phase I (CGIAR-IEA 2015a). Presumably, those results will be more informative for decision-making in Phase II, especially if budgets become tighter.

More than 25 ICRISAT-related studies were conducted in Phase I in the Dryland Cereals and Grain Legumes CRPs that touched on multiple aspects of priority setting. Many of these are referred to in this report; the majority were specific to a geographic area, crop, and/or candidate technology. A more comprehensive economic exercise in priority setting was not carried out.

Economic priority setting addresses research resource allocation. Specifically, should more resources be invested in a research area or technology vis-à-vis other research areas and technologies? In other words, what is the opportunity cost of investing more in a well-defined research area or technology? When resources are constraining, what are the prime candidates in terms of specific research areas and technologies for divestment?

Examples in the literature of priority setting across the entire research portfolio of a CG Center include Walker and Collion (1996) and Fuglie (2008). The RTB CRP drew heavily on these earlier experiences at CIP to structure and update their work on priority setting which is characterized by the following three attributes: (1) the research agenda is represented by a limited number, usually 20-30, well-defined prospective technologies, (2) the prospective technologies are assumed to be separable or independent, and (3) each prospective technology involves an annual cost of at least 2 to 3 Full-Time Equivalent International Recruited Scientists (FTE-IRS).

These attributes warrant more explanation. The naive perception in agricultural research that everything is related to everything else, that technologies need to be integrated across space and over time, and that simultaneous actions are required to generate new technologies is inimical to the identification of problems and opportunities that lead to the well-defined prospective technologies. The definition of priority research areas and related technologies requires a holistic vision of constraints and opportunities. But once problems are diagnosed and opportunities appraised, the pursuit of integration results in technology packages that are only adopted piecemeal if at all. The outcomes of agricultural research are too uncertain to invest an inordinate amount of time in priority setting.

In RTB's Phase I priority setting, improved soil and water management on cassava was the most ill-defined technology. Ambiguity suggests that the major technological components in soil and water management on cassava vary from country to country, region to region, and place to place. Such location-specificity runs counter to the criterion of international public goods that is the raison d'etre of the CGIAR. Without clarity in the definition of prospective technologies, institutional attribution in *ex-post* impact assessment cannot be established.

Prospective technologies do not have be identified with single components or necessarily thought of as 'silver bullets', but they require more detailed description than references to a subject matter area such as soil and water management at the level of a commodity. Fuzzy descriptions of prospective technologies underscore the priority for more incisive diagnostic research that does need to consider trade-offs in biological, physical, edaphic, and socioeconomic characteristics that are part and parcel of a well-defined researchable problem.

The 2-3 FTE IRS minimal investment level indicates that research management is seriously committed to the prospective technology. Usually, research investment exceeds this minimal level especially after all possible scientist-research support time is accounted for in the development of the prospective technology.

It is worthwhile noting that ICRISAT did engage in comprehensive and innovative priority setting in the mid-1990s during a time of tightening budgets (Kelley et al. 1995). Compared to the CIP- and RTB-related applications described above, ICRISAT's priority setting relied more heavily on expert opinion, scoring of qualitative criteria along with conventional economic analysis, and a highly detailed and disaggregated definition of prospective technology. It was also relatively time intensive. The degree to which ICRISAT's detailed priority setting for the 1994-98 Medium Term Plan influenced subsequent priority setting is not known, but, unlike the CIP applications that were the basis for the RTB priority-setting in Phase I, it was never repeated.

Crop Priorities for Phase II

The crop priorities for the proposed consolidated Grain Legumes and Dryland Cereals CRP for Phase II are briefly evaluated in this section from four perspectives: (1) economic importance, (2) dryland intensity, (3) demand, and (4) alternative suppliers. In addition, we also discuss the demand for traits which was highlighted as an area warranting more explanation in the ISPC commentary.

Economic Importance: Congruence

Four cereals, barley, finger millet, pearl millet, and sorghum and eight grain legumes, common bean, chickpea, cowpea, faba bean, groundnut, lentil, soybean, and pigeonpea represented the cropwise areas of interest in Phase I. Are all of these commodities of sufficient importance in the target countries to warrant their inclusion in Phase II? This question was addressed in an earlier version of this sub-section that carried out a simple congruence analysis using value of production as a criterion for potential economic impact.

Congruence is a normative criterion that says that research investment should be roughly proportional to the economic importance of the crop or activity to maximize the potential impact of research (Arndt and Ruttan 1977). Departures from congruence reflect the importance of other criteria related to desirability or to technical feasibility (Alston et al. 1995 and Walker and Collion 1996). Several of those criteria will be thoroughly examined in 2017 when the DCL CRP conducts a detailed priority setting exercise patterned after RTB's pioneering work in this area.

It is also worth noting that different criteria do not necessarily yield markedly different results than those furnished by a congruence analysis. For instance, economic congruence and poverty reduction criteria have given very similar cropwise, research-resource allocations for small and medium-sized farm households in Mozambique (Walker et al. 2006).

Across 71 crop by target country observations, chickpea in India was characterized by the highest value of production in 2014 (Table 1). Other observations that ranked in the top 10 were groundnut, pearl millet, pigeonpea, and sorghum in India, groundnut and sorghum in Nigeria, sorghum in the Sudan and Ethiopia, and pearl millet in Niger.

This ranking among the highest valued observations was expected, but, somewhat surprisingly, groundnut's value of production was higher than any of the other 12 crops. It exceeded 10 billion US$ in 2014 and was characterized by a value share of 22% (Table 1). The importance of groundnut as the leading crop in Table 1 reinforces the need for an innovative and active seed program as scarce planting material can be a binding constraint to varietal change. Of the 12 crops in Phase I, groundnut has the lowest multiplication ratio and the highest seed rate per hectare. Groundnut's top rank in Table 1 lends weight to the ISPC's suggestion that a seed specialist could be a productive investment in Phase II (ISPC 2016).

Total value of production across the 12 crops is greater in Sub-Saharan Africa (54%) than in South Asia (44%). With 27% shares, value of production is evenly split between WCA and ESA in SSA.

Value of production in the target crop by country observations approaches 50 billion US$ (Table 1). It is about 8 times greater than the total for the 44 spillover crop by country observations (Table 2).

Table 1. Relative economic importance of the proposed DCL crops in 2014 in the target countries of production.

				% Share	
Rank	**Crop**	**Countries (#)**	**Value of production (US$ million)**	**Percent share of value of production**	**Cumulative**
1	Groundnut	10	10,680.3	22.0	22.0
2	Sorghum	8	9,086.8	18.7	40.7
3	Chickpea	6	7,428.2	15.3	56.0
4	Pearl millet	8	7,164.6	14.8	70.8
5	Pigeonpea	6	3,181.3	6.6	77.3
6	Common Bean	6	3,044.5	6.3	83.6
7	Cowpea	8	2,992.1	6.2	89.8
8	Barley	3	1,469.2	3.0	92.8
9	Finger millet	4	1,338.9	2.8	95.6
10	Lentil	3	1,001.7	2.1	97.6
11	Faba bean	3	643.4	1.3	98.9
12	Soybean	6	510.6	1.1	100.0
TOTAL		71	48,541.6	100.0	

Table 2. Relative economic importance of the proposed DCL crops in 2014 in the spill-over counties of production.

				% Share	
Rank	**Crop**	**Countries (#)**	**Value of production (US$ million)**	**Percent share of value of production**	**Cumulative**
1	Groundnut	10	10,680.3	22.0	22.0
2	Sorghum	8	9,086.8	18.7	40.7
3	Chickpea	6	7,428.2	15.3	56.0
4	Pearl millet	8	7,164.6	14.8	70.8
5	Pigeonpea	6	3,181.3	6.6	77.3
6	Common bean	6	3,044.5	6.3	83.6
7	Cowpea	8	2,992.1	6.2	89.8
8	Barley	3	1,469.2	3.0	92.8
9	Finger millet	4	1,338.9	2.8	95.6
10	Lentil	3	1,001.7	2.1	97.6
11	Faba bean	3	643.4	1.3	98.9
12	Soybean	6	510.6	1.1	100.0
TOTAL		71	48,541.6	100.0	

Seven crops account for 90% of value of production in the countries of primary interest. Of the other five, barley warrants inclusion in the DCL portfolio because of the sustained progress made in Ethiopia, the dominant target country of interest, and because its spillover potential is larger than any other crop (Table 2). Between 1998 and 2010, the use of improved varieties of barley in Ethiopia increased from 10 to 35% (Yigezu et al. 2015). Farmers have adopted both improved food and malting barleys.

If resources are constrained, and they almost always are, the inclusion of the four lowest ranking crops for W1/W2 funding is problematic. Strictly speaking, the estimates in Table 1 imply that about 93% of the potential for economic impact can be obtained with support for the top eight-ranking crops in the DCL portfolio.

What drives the results of any congruence analysis of economic importance is the extent of the activity or the area of the crop. These results are no exception. The simple correlation coefficient between value of production and area harvested is 0.88. Among the four lowest ranking crops in Table 1, only finger millet slightly exceeds an area of two million hectares; faba bean is planted on only 0.7 million hectares. At the other end of the spectrum, sorghum, pearl millet, groundnut, chickpea, and cowpea are cultivated on more than 10 million hectares with sorghum, at 25 million hectares, being the most extensively grown crop.

The prospects for area expansion in soybean in SSA seems brighter than for lentil, finger millet, or faba bean in their respective target countries. The demand for lentil is strong, but Australia has emerged as a dominant international producer. Finger millet is characterized by a strong upward trend in productivity in India that has more than offset declining area. In ESA, finger millet is not internationally traded, but its domestic demand appears to be stronger than sorghum and pearl millet in that region.

The uptake of technology in faba bean has been very slow in Ethiopia (Yigezu et al. 2015), the most important producer among the few target countries that cultivate the crop. By 2010, adoption of improved faba bean cultivars was estimated by breeders at 3-5%, which was confirmed by a nationally representative joint survey of barley, faba bean, and potato. Improved cultivars that found a home in farmers' fields were released in the 1980s. On a positive note, faba bean as a crop did fit in quite seamlessly in the GL research portfolio in Phase I; it was well-represented in three of the eight product lines.

In contrast, soybean's profile is more dynamic punctuated by the rapid acceptance of improved, but increasingly old, varieties and increased plant populations. Most countries will continue to be net importers of soybean in the medium-term future which has fueled national governments' interest in the crop in SSA. Soybean's versatility underlies its expansion in almost all global regions where field crops are grown. Since the early 2000s several countries have doubled and tripled area and production from a very small base (Smart and Hanlon 2013), but surpassing a two million hectare milestone by 2022 is not guaranteed in SSA.

An emphasis on youth and on nutrition would argue for keeping soybean in the portfolio. Soybean has a greater presence in the rural non-farm economy with sizable downstream linkages, especially in processing, than any other crop in the combined DC & GL portfolios. The rural non-farm economy is critical for rural labor absorption (Tschirley and Reardon 2016). Soybean is also sufficiently versatile to figure prominently as a food crop in women's nutrition programs targeted at young children below two years of age at risk of malnutrition. Once it is established in the market, the Africa RISING program in Ghana shows that soybean is readily cultivated by women and destined for diverse uses including feeding programs.

This simple analysis of value of production also generates a few other minor implications. First, with the focus on eight crops, the congruence between the commodity and the farming systems portfolios in dryland agriculture improves marginally. For example, faba bean production in The Sudan is located in the north of The Sudan and is irrigated. As discussed in the next sub-section, about 1/3rd of soybean production in SSA takes place in the wet sub-humid tropics and sub-tropics (Walker 2016). Secondly, the number of target countries declines from 15 to 14 because Zambia is not a priority country for any of the eight top-ranking crops in Table 1. Lastly, about 1/3rd of the spill-over crop by country observations do not have sufficient production (at least

30,000 tonnes) to maintain a viable crop improvement program (Brennan 1992). Spillovers are unlikely if size-of-program considerations do not warrant a sustained investment in crop improvement.

Dryland Intensity

The ISPC has also expressed concern that one or more of the grain legumes in the consolidated CRP in Phase II would not be considered 'dryland' or would not be typical of dryland agriculture. For sub-Saharan Africa, it is easy to quantify dryland intensity with the HarvestChoice database (Walker 2016). Dryland agriculture is defined as having an Aridity Index between 0.05 and 0.65. The Aridity Index expresses the ratio of rainfall to potential evapotranspiration. Alternatively, it can be viewed as the ratio of the supply of water to the crop to the demand for water by the crop. Higher values of the index indicate wetter growing conditions; lower values are synonymous with dryer growing environments.

Below the lower boundary of an aridity index of 0.05, all field crops would require some irrigation to produce grain. Above an aridity index of 0.65, seasonal moisture deficits do not constrain crop production. Too much instead of too little rain is more likely to be the problem when the estimated aridity index exceeds 0.65. Surpassing this upper boundary may be associated with negligible drought risk but erosive rainfall events, waterlogged fields, and leached soils may be inimical to heavy yields.

Between 0.05 and 0.65, four aridity indexes (3, 4, 5, and 6) refer to dryland crop production in the HarvestChoice database. Each is separated by an interval of 0.15. The last category (AI=7) reflects rainfed production which is reckoned to be too wet to be termed dryland. Therefore, cropped area can be disaggregated into three broad categories: (1) irrigated area that may be found in any of the AI categories (1-7), (2) dryland area (AI categories 3-6), and (3) wet rainfed (AI category 7). In 2000, about 140 million hectares were well described with crop names in the HarvestChoice database in SSA. Only about 4-5% of cropped area was irrigated. Two-thirds of rainfed area could be called dryland (AI categories 3-6) and one-third could be termed wet rainfed (Category 7). As expected, the means for the dryland categories exhibit a wide variation in length of the growing season and rainfall (Table 3).

Table 3. Composition of rainfed crop area by Aridity Index classes, length of the growing season, and rainfall in SSA circa 2000.

Description of Drylands	Aridity Index Category (class)	Average length of the growing season in days	Average rainfall in mms	Share (%) of rainfed cropped area
Arid Zone	3	46	272	11
Dry Semi-Arid	4	99	546	18
Wet Semi-Arid	5	154	809	18
Dry Sub-Humid	6	196	1051	21
Non Drylands: Rainfed wet	7	267	1520	33

Source: Constructed from the HarvestChoice database

All the Phase I crops have at least 50% of their area in the four dryland agroecologies in SSA ranging from slightly over half to beans to over 90% for millet (Table 4). Other pulses mainly refer to cowpea. Coarse cereals, pulses, and oilseeds are the main commodity groups grown in the drylands. Cotton is the main cash crops; sesame and sunflower are increasingly important oilseeds particularly in East and Southern Africa. Faba bean would have a dryland share similar to barley as they are both cultivated at about the altitude in the highlands of Ethiopia. Chickpea is mostly cultivated on residual moisture in India. Pigeonpea would have a dryland share between groundnut and cowpea. None of the DC and GL crops are irrigated on over 5% of their area in SSA. Cropwise irrigation is only prevalent in one country: about 15-20% of the sorghum growing area in The Sudan is irrigated.

Table 4. The relative importance of dryland cropping in SSA in 2000.				
Crop	**Dryland (Aridity Indices 3-6) %**	**Rainfed Wet (Aridity Index 7) (%)**	**Irrigated (%)**	**Total cropped area (Ha)**
Millet	92.6	7.3	0.1	17,959,054
Other pulses	85.2	14.4	0.3	10,432,527
Sorghum	84.8	10.4	4.8	20,929,856
Other fiber	81.9	18.1	0	343,829
Other oilseeds	72.6	27.4	0	10,255,960
Groundnut	71.3	23.7	5.0	8,124,154
Cotton	69.9	22.3	7.8	3,984,223
Soybean	69.2	29.8	1.0	1,606,805
Maize	59.8	38.4	1.8	25,330,029
Barley	55.5	44.1	0.4	1,044,183
Wheat	54.5	25.0	20.5	2,546,549
Bean	52.6	47.3	0.1	5,148,596
Potato	47.5	51.0	1.5	1,038,216
Banana	38.2	61.7	0.1	5,269,893
Coffee	35.7	64.1	0.2	2,526,521
Sweet potato/yam	32.8	57.7	9.5	4,778,065
Cassava	28.7	71.3	0	10,343,873
Rice	24.1	43.8	32.1	6,408,267
Sugarcane	16.0	41.7	42.3	1,020,741
Total	-	-	-	**139,091,341**

Source: Constructed from HarvestChoice database (You et al. 2007).

Updating Table 4 with the HarvestChoice data for 2005 or 2010, when they become available, would change the area proportions as maize would gain ground among the coarse cereals. However, the dryland shares would remain essentially the same, as the extent of irrigated area in SSA presently does not exceed 10% and crops grown in the Arid, Semi-Arid, and Sub-Humid Tropics have not migrated to the Humid Tropics.

Demand

The above congruence analysis of value of production is a first-cut at priority setting that very broadly indicates the potential for technological change. Assessing demand for the crops of interest vis-à-vis competing commodities is an important aspect of priority setting. Is there sufficient demand to make a sizable contribution to poverty reduction and nutritional enhancement? Is demand weakening over time in response to so-called mega trends so that these contributions are likely to be threatened?

Rainy-season sorghum in India is the classic case of a crop going out of production because of weak demand in a dynamic production and consumption environment. At Independence in 1947, sorghum was the second most extensively grown cereal in India ranking behind rice. Seventy years later *kharif* sorghum has been replaced by wheat in consumption and lost out to soybean, Bt cotton, and to the substitution of tractors for bullocks in production. For all intents and purposes, ICRISAT has divested from most of its crop improvement of rainy season sorghum that is now cultivated on a much-diminished area in peninsular India. More recently, ICRISAT has also divested of sweet sorghum intended as a raw material for biofuel.

Because of the valid stereotype of sharply reduced urban demand for sorghum and millet, concern is usually expressed about their medium-term prospects. We focus in this sub-section on these two dryland cereals because demand for grain legumes is strong into the medium-term future. Prices of grain legumes are attractive to producers; supply has always been the constraint. There are few if any documented instances where widespread gluts in production have led to severely depressed prices. Some post-harvest innovations, such as pre-cooked biofortified beans, can save women's time and firewood, but they increase demand for the pulse that is the preferred and highest priced grain legume in the market in East Africa. Per capita consumption of pulses is very gradually declining in India, but the gulf between domestic consumption and production is steadily widening.

Demand for cowpea in West Africa with the FAOSTAT database. Cowpea is the lowest priced pulse in the target countries; therefore, it would be the pulse crop of interest to seek confirmation that demand is not a binding constraint to prospective technological change. In West Africa, pulse consumption in the so-called Inland Sahelian countries is higher than on the more humid coast (Table 5). Per capita consumption is also increasing at a healthy clip in the largest countries in the Sahelian, Sudanian, and Guinean Zones in West Africa. Cowpea is the dominant pulse in these broad sub-regions.

Table 5. Per capita pulse availability (2005-09) and CAGR[a] (1980-84 – 2005-09)

Country	Pulses	
	(kg/year)	CAGR[a]
Niger	29.5	1.5%
Benin	14.5	3.3%
Burkina Faso	13.0	1.3%
Sierra Leone	12.5	1.8%
Cape Verde	9.5	- 1.2%
Nigeria	9.5	3.5%
Mali	8.5	3.1%
Guinea	6.0	- 0.6%
Togo	6.0	- 1.1%
Senegal	4.7	0.6%
Liberia	2.8	3.0%
The Gambia	2.3	- 3.0%
Guinea Bissau	2.2	0.2%
Cote D'Ivoire	2.1	4.1%
Ghana	0.6	- 0.8%

Source: Hollister and Staatz (2015). Calculated from FAOSTAT, food balance sheet data.

[a]Compound annual growth rate (CAGRO in pulse availability between 1980-84 and 2005-09.

Demand for pearl millet and sorghum in West Africa with the FAOSTAT database. Although the quality of FAOSTAT data vary considerably by country and even by crop within a country, a recent time-series analysis of the FAO food balance estimates is informative about the relative importance of pearl millet and sorghum in the 15 ECOWAS countries in West and Central Africa (Hollister and Staatz 2015). Of the 15 countries, nine were characterized by levels of apparent consumption for sorghum and millet together that exceeded 15 kgs per capita per annum (Table 6). In Niger, Burkina Faso, Mali, and Nigeria, sorghum and/or millet are the dominant cereals; apparent consumption of both crops is superior to 75 kgs per capita.

On the other hand, the estimated growth rates for rice, wheat, and maize in Table 6 are higher than those for sorghum and pearl millet, suggestive of the former gaining ground in apparent consumption at the expense of the latter. However, for the so-called 'Big Four' countries in Table 6, sorghum and millet still contribute a large share of caloric availability in total starchy staples ranging from 30% in Nigeria where they rival root and tuber crops in importance to 84% in Niger. Hollister and Staatz (2015) are quick to point out that although their contribution to caloric availability is declining in most countries except Niger and The Gambia "sorghum and millet are still the prevailing source of calories in the Inland Sahel and they also remain important in The Gambia and Nigeria (p. 134)."

In the lower ranking countries in Table 6, there may be smaller geographic areas, such as the northeast of Ghana where sorghum and/or millet are still prominent in household production and consumption. Spillover benefits from successful crop improvement in the core Inland Sahelian countries could generate large per household benefits for Strategic Objectives 1 & 2 in these smaller sub-regions.

Table 6. The level and growth in per capita apparent consumption of cereals in West Africa by crop and country from 2005-2009.

	Rice		Wheat		Maize		Millet		Sorghum	
	Kg/yr	CAGR (%)	Kg/yr	CAGR (%)	Kg/yr	CAGR (%)	Kg/yr	CAGR (%)	Kg/yr	CAGR (%)
Niger	16	2.0	5	-1.0	3	1.2	139	0.0	41	0.0
Burkina Faso	9	2.3	7	2.3	47	4.5	69	1.3	88	1.0
Mali	55	3.4	9	1.3	29	3.5	63	0.7	44	0.3
Nigeria	22	1.5	20	1.1	25	4.7	36	1.3	41	0.6
The Gambia	49	-2.1	24	2.0	11	0.6	58	2.6	15	1.1
Senegal	72	0.3	32	1.9	28	2.6	27	-2.8	9	-3.8
Togo	22	3.6	10	-0.6	66	1.8	6	-2.9	22	-0.4
Benin	32	5.2	7	-2.0	58	0.2	3	3.3	15	-0.4
Ghana	26	5.6	17	2.6	35	0.7	6	-0.6	10	0.7
Ghana	26	5.6	17	2.6	35	0.7	6	-0.6	10	0.7

Source: Constructed from Hollister and Staatz (2015), Table 5.1. (p.132). CAGR=Compound Annual Growth Rate from 1980-1984 to 2005-2009.

Nevertheless, for a country like Senegal with high negative growth rates in apparent consumption in Table 6, it is now too late to be expecting a large impact from successful crop improvement of pearl millet. Senegal was listed as a target country for the product line on Pearl Millet in Africa in Phase I, but work was justifiably concentrated in countries with a more intensive millet profile in production and consumption. Conceptually, it makes sense to think of Senegal as a spillover country in Phase II for the Pearl Millet in Africa product line.

Demand for pearl millet and sorghum in West Africa from national survey data on consumption expenditure. Based on evidence from household surveys analyzed from 2002-2010 for selected countries (Hollister and Staatz 2015), sorghum and pearl millet, as expected, loom large in rural household food expenditure in Burkina Faso, Mali, and Niger (Table 7). With the exception of Burkina Faso, relative importance is greater for the poorer two quartiles than for the other 60% of households. In Burkina Faso, Mali, and Niger, the rise in average expenditure on food by quartile more than compensates for any fall in the share by quartile, such that the highest rural expenditure quartile is spending more on sorghum and millet than the lowest. In other words, expenditure elasticities are positive for the rural households as there is scope for increasing sorghum and millet intake as income rises.

Urbanization is accompanied by a fall in the food shares by about 50% for millet/sorghum (Table 8). This decline is sharper for millet/sorghum than for any other commodity group. The millet/sorghum share in urban food expenditure also decreases from the lower to the higher expenditure urban quintiles. That decline is steeper in Burkina Faso and Mali and is more gradual in Niger.

Comparing the estimated food expenditure shares for rural households in Table 7 with those for rural households in Table 8 begs the question about the speed of urbanization in Africa. Faster urbanization accelerates the demise of millet and sorghum as staples of national importance and diminishes the leverage that their improvement in productivity has on poverty and malnutrition.

Table 7. Shares (in %) of rural food expenditure by commodity group for nationally representative consumption expenditure surveys										
				Commodity Group						
Country	Survey Year	Quintile	Rice	Maize	Millet/ sorghum	Wheat	Roots/ tubers	Fruits/ vegetables	Animal Products
Burkina Faso	2009	1	5.0	7.3	35	1.2	0.4	7.1	7.3
		2	5.9	9.2	38.7	1.1	0.3	6.5	7.0
		3	7.4	10.5	36.4	1.3	0.6	5.7	7.2
		4	8.5	10.2	33.9	1.5	0.6	5.4	9.3
		5	10.2	10.2	35.8	1.5	0.6	4.4	10.2
Ghana	2006	1	8.6	9.3	6.3	2.8	5.1	15.7	24.6
		2	10.1	7.5	1.5	3.9	8.1	15.4	31.5
		3	11.6	6.9	0.8	4.1	9.9	14.3	32.7
		4	10.6	6.0	0.7	4.4	12.1	14.7	31.3
		5	10.5	5.3	0.5	4.6	13.3	13.3	30.7
Mali	2006	1	10.6	6.1	29.1	1.6	1.0	9.0	13.1
		2	14.2	4.9	28.1	1.9	0.7	8.0	14.8
		3	17.6	5.4	24.6	2.0	1.1	8.0	14.8
		4	17.4	5.7	24.1	2.2	0.9	7.3	16.5
		5	19.5	3.7	17.4	3.0	1.3	7.9	22.6
Niger	2005	1	4.2	4.2	58.1	0.4	0.6	2.5	10.1
		2	5.0	3.7	56.8	0.5	1.0	3.1	10.2
		3	6.4	4.4	54.4	0.8	0.6	3.1	11.2
		4	7.2	3.8	50.3	1.4	0.7	4.0	11.1
		5	8.9	5.5	44.1	1.6	0.8	4.7	12.2
Senegal	2002	1	25.8	1.1	10.0	4.5	1.3	9.9	3.6
		2	21.5	1.2	8.5	6.8	1.8	10.8	4.6
		3	21.8	1.2	7.6	7.5	1.9	11.0	4.9
		4	20.7	0.9	7.6	7.0	1.9	11.0	6.0
		5	22.6	0.6	6.3	7.6	1.9	10.4	8.4

Source: Constructed from Hollister and Staatz (2015), Table A6.2

The pace of urbanization in Sub-Saharan Africa is slower than for Latin America or Southeast Asia. It is only slightly faster than urbanization in South Asia. By 2040, about 50% of the population of SSA is projected to live in urban areas; a comparable estimate for South Asia is 45% (Tschirley and Reardon 2016).

The results in Tables 7 and 8 are confirmed by the analysis of two more recent LSMS-ISA surveys from 2011 in Niger and 2012/13 in Nigeria (Cheng and Larochelle 2016). Their analysis is one of the most informative socioeconomic inquiries undertaken by the Dryland Cereals CRP in Phase I.

The poverty intensity of consumption expenditure for sorghum and millet is explicit in Table 9 for both rural and urban households. In Niger, almost all rural and urban people eat millet. Millet looms larger for the rural poor than for the non-poor in consumption expenditure although in monetary terms the value of millet consumption is higher for the non-poor than for the poor. The same consumption tendencies apply to sorghum albeit at a substantially lower level for rural households in Niger.

For urban residents of Niger, per capita consumption expenditure on millet falls by about 2/3rds. In monetary terms, the value of consumption also declines somewhat from US$25 for the urban poor to US$22 for the urban non-poor. For the urban poor, the share of millet in food expenditure is still high at about 16%.

Table 8. Shares (in %) of urban food expenditure by commodity group for nationally representative consumption expenditure surveys									
Country		Survey year	Quintile	Commodity Group					
			Rice	Maize	Millet/ sorghum	Wheat	Roots/ tubers	Fruits/ vegetables	Animal products
Burkina Faso	2009	1	16.4	16.6	14.6	2.3	0.6	8.7	6.8
		2	18.9	18.1	14.8	2.4	0.4	7.6	7.5
		3	21.7	16.2	9.1	3.6	0.7	8.5	8.8
		4	21.8	15.4	5.9	4.4	0.8	8.9	11.8
		5	25.2	16.6	3.1	5.2	1.1	7.6	16.1
Ghana	2006	1	13.9	8.1	0.5	5.4	13	14.9	25.6
		2	12.5	6.8	0.2	5.7	14.4	14.1	26.7
		3	12.2	5.5	0.2	6.1	12.3	14.2	28.4
		4	11.6	4.8	0.3	5.7	12.6	13.8	29.1
		5	11.1	3.7	0.1	5.9	12.9	13.3	27.4
Mali	2006	1	20.5	5.5	14.8	3.8	1.0	11.1	16.1
		2	24.8	2.5	13.5	4.5	1.4	10.8	17.5
		3	22.5	2.7	11.5	3.9	2.3	11.6	20.7
		4	21.9	2.1	8.2	5.0	3.2	12.3	22.2
		5	14.0	1.9	6.3	4.8	3.8	11.5	36.5
Niger	2005	1	18.7	10.6	29.9	1.0	0.8	7.1	7.8
		2	21.2	11	22.2	1.8	0.5	6.9	10.4
		3	20.4	11.5	18.8	2.4	0.9	7.6	12.7
		4	18.7	11.2	14.9	4.2	1.3	8.4	14.3
		5	16.1	10.1	10.4	5.8	1.7	9.6	19
Senegal	2002	1	18.9	0.1	3.1	11.3	2.3	12.4	9.3
		2	15.3	0.1	2.6	12.8	2.6	13.3	12.7
		3	13.5	0.2	2.4	13.1	2.7	13.3	16.2
		4	10.9	0.2	1.9	11.8	3.0	14.4	20.4
		5	12.7	0.2	1.3	9.1	3.1	14.6	27.5

Source: Constructed from Hollister and Staatz (2015), Table A6.1

Table 9. Millet and sorghum consumption in Niger and Nigeria, by rural/urban and poor/non-poor.								
Crops	Group	Poverty	% of households consuming the product		Per capita expenditure (US$)		% in household food expenditure	
			Niger	Nigeria	Niger	Nigeria	Niger	Nigeria
Millet	Rural	Poor	99.16	46.57	56	12	35.33	5.48
		Non-poor	99.79	29.00	69	11	24.01	2.25
		All rural	99.50	35.45	62	11	28.18	3.44
	Urban	Poor	92.24	27.54	25	5	15.98	2.01
		Non-poor	87.17	9.66	22	3	6.46	0.47
		All urban	87.85	11.15	23	3	7.75	0.60
Sorghum	Rural	Poor	55.80	61.03	9	17	5.51	7.77
		Non-poor	61.43	36.53	13	13	4.38	2.77
		All rural	58.85	45.53	11	15	4.89	4.61
	Urban	Poor	24.39	34.41	2	8	1.66	3.21
		Non-poor	16.88	12.91	2	3	0.62	0.55
		All urban	17.89	14.70	2	4	0.76	0.77

Adapted from Cheng and LaRochelle, 2016.

In Nigeria, sorghum is more important than millet. Together, the value of millet and sorghum consumed equates to about 13% of expenditure on food for the rural poor. For the rural non-poor and the urban poor, the estimated share only slightly exceeds or approaches 5% (Table 9).

The national estimates in Table 9 mask a sharp regional variation in food consumption expenditure in Nigeria. Maize, millet, and sorghum are staples in the North; cassava and yams are heavily consumed in the humid tropics of the South. In the Northwest region, sorghum or millet is eaten by 7 of 8 households (Table 10). On average, their expenditure approaches US$50 per annum per capital on sorghum and millet leading to a food expenditure share for sorghum and millet of about 15%. In northern Nigeria, tens of millions of rural households rely heavily on sorghum and millet.

In contrast, in Niger millet is intensively consumed throughout the country with exception of more urbanized Niamey. Mean per capita expenditure in Diffa, Dosso, Maradi, Tahoua, Tillaberi and Zinda ranges from US$53 to US$64 (Table 10).

Clearly, millet and sorghum will be important food crops in West Africa well into the 21st Century. They will continue to lose ground to maize in the wet Semi-Arid Tropics and in the Dry Sub-Humid Tropics described in Table 3, but they have no competitors in the Arid and Dry Semi-Arid Tropics. Later in the 21st Century their situation will be similar to rainy-season pearl millet and post-rainy season sorghum in India. As long as people inhabit rural areas characterized by the potential for chronic and severe drought stress, these two coarse cereals will find a home in farmers' fields.

Table 10. Millet and sorghum consumption in Niger and Nigeria, by regions/zones.

		Millet			Sorghum		
Country	**Regions/ zones**	**% of households consuming the product**	**Per capita expenditure (US$)**	**% in household food expenditure**	**% of households consuming the product**	**Per capita expenditure (US$)**	**% in household food expenditure**
Niger	Agadez	98.57	37	13.13	23.43	3	1.36
	Diffa	98.73	62	23.81	28.21	5	1.67
	Dossa	98.79	60	27.70	43.62	8	3.52
	Maradi	99.20	53	26.75	51.38	8	3.57
	Tahoua	99.20	64	28.08	75.33	16	7.21
	Tillaberi	98.22	61	29.38	39.25	6	3.17
	Zinder	98.75	55	26.05	63.20	11	4.83
	Niamey	76.35	13	3.53	8.34	1	0.29
Nigeria	N. Central	23.12	5	1.39	57.55	13	3.43
	N. East	51.79	17	5.68	67.84	20	7.26
	N. West	85.84	22	7.66	87.86	26	9.25
	S. East	0.41	0*	0.01	1.44	0^	0.02
	S. South	0.68	0*	0.00	0.31	0*	0.00
	S. West	0.11	0*	0.00	2.93	0*	0.06

*These values are so small that they became zero after converting local currency (Naira) to US$

Source: Cheng and LaRochelle, 2016.

Revising estimated growth rates in food demand for millet and sorghum in West Africa. Having confirmed sorghum's and millet's 'permanence' in consumption, the growth estimates in Cheng and LaRochelle (2016) need to be taken with a large grain of salt. Per their footnote 15, the growth rate of demand for food is the population growth rate plus the multiplication of the per capita income growth rate by the estimated expenditure elasticity. The expenditure elasticity of 0.3 for millet in the rural sector seems correct, but higher values in urban than in rural areas and estimates that do not differ significantly from 1.0 for both crops in Nigeria result in implausibly high growth estimates that average 5.0% in both countries. For urban Nigeria, the estimated growth rate for each crop is calculated at 8.0% per annum.

The high expenditure elasticities for urban consumption appear to be an artifact of constrained estimation that is intrinsic to the use of an integrated demand system that is very appropriate for this application. Unconstrained estimation would generate significantly lower expenditure elasticities especially for urban consumption. Based on the mean quartile expenditure data in Table 4 (page 8), regressing the value of sorghum and millet consumption on total food expenditure both in logarithms controlling for the additive effect of the crop gives a positive expenditure elasticity of 0.55 for rural households in Niger but negative and statistically significant results in urban Niger, rural Nigeria, and urban Nigeria. Because of population growth, these estimates still result in positive growth rates, but they are less than those reported in Cheng and LaRochelle (2016). Regressing sorghum and millet expenditure on total consumption expenditure would give even lower but still positive growth rates.

The 'falling off a cliff' syndrome stemming from urbanization is not unique to sorghum and millet. Some root crops like sweet potato suffer from the same fate. Foxtail millet in northern China and sweet potato in all provinces of China are crops that are rapidly declining in importance with high rates of urbanization, income growth, and interregional mobility. Enhancing crop versatility in consumption to overcome constrained urban demand is a very challenging proposition. Cassava in SSA appears to be one of the few emerging success stories.

The Demand for Traits

In agricultural research, the demand for characteristics by users is of paramount importance. Weak demand translates into limited adoption and negligible impact. Since the beginning of Project HOPE and Tropical Legumes I, information on the demand for characteristics has been widening and deepening across many of 71 target crop by country combinations described in Table 1. For beans, gender-specific preferences for varietal characteristics have been tabulated and analyzed in all target and most spillover countries in the Pan African Bean Research Alliance (PABRA) Network. For the other crops, gender-specific preferences are also well known in many of the target countries.

Farmers' perceptions of traits have been routinely canvassed in baseline and early adoption studies. Of the two types of inquiries, information from adoption and diffusion research is more valuable because perceptions can be elicited in a comparative fashion on new varieties vis-à-vis those being replaced. All varieties have perceived strengths and weaknesses. An illustrative and innovative application in the context of a nationally representative survey across all groundnut-growing agro-climatic zones in Nigeria is Ndjeunga et al. (2013):

"Overall, all the 3 recent varieties (SAMNUT 21, SAMNUT 22, SAMNUT 23) are preferred for the vigor (+), resistance/tolerance to diseases and pests (+), growth habit (+), plant maturity (+) and higher number of pods (+) and disliked for haulm yield (-). As for the local varieties, producers like their pod size, pod filling, grain color, pod yield and haulm yield but dislike their poor vigor, the color of the leaves, low resistance to diseases and pests, late maturity and lower number of pods. In effect, improved varieties have the characteristics preferred by groundnut producers except for haulm yield. This characteristic is important especially for farmers who are both crop and livestock producers (p.36)".

Earlier work in Ndjeunga et al. (2010) elicited trait demand in the context of panel households active in Participatory Varietal Selection (PVS) in Mali, Niger, and Nigeria. Demand for specific traits varied somewhat from country to country, but pod yield was prized in the three countries. Haulm yield was economically more important in Nigeria than in Mali and Niger. Even earlier work that was cast in the framework of the Groundnut Seed Project prior to Tropical Legumes I showed that high grain yield was the most valued trait in Nigeria and Mali (Ndjeunga et al. 2008). The second most valued trait was resistance to rosette in Nigeria and earliness in Mali. Disease and pest resistance ranked first in Niger followed by pod yield. In summary, high pod yield, disease and pest resistance, early maturity, high market value and high oil content were the most common variety traits sought by farmers in the three countries (Ndjeunga et al. 2008).

In a joint impact assessment of improved pearl millet and sorghum cultivars in six states in northern Nigeria, farmers gave the popular pearl millet variety SOSAT C88 high marks on early maturity, insect tolerance, large grain size, grain color, good cooking time, but faulted it for lower fodder yield, low storability, and a shorter head size (Ndjeunga et al. 2011). Through not statistically significant, grain yield, high head filling, and ease of processing were also positively valued by producers. Perceived differences in relative strengths and weaknesses were more marked for improved sorghum variety ICSV 400. Farmers viewed its attractive selling price, early maturity, and insect tolerance as strengths, but cited its drought susceptibility, short stalk, and narrow stem as areas for improvement.

Of interest in this assessment, farmers believed that their local pearl millet varieties gave grain yields inferior to the improved cultivars, but that productivity levels among new varieties released in the 1990s and early 2000s were more or less the same. Grain yield in sorghum was not believed to be different between local and improved varieties or among the set of improved varieties. This difference in perception translated into varying net benefits documented for varietal change in the two crops. Transparent and substantially higher net benefits for modern pearl millet varieties reinforced expectations of sustained diffusion, but fuzzier perceptions about productivity differences in local and improved sorghum varieties fueled doubt about the prospects for continuing varietal diffusion with the termination of funding for aggressive extension programs.

Although perhaps not as comprehensive as these studies, funding from the Bill & Melinda Gates Foundation since 2006/07 has filled the profile on demand information for traits for countries and crops in Phases I and II of the HOPE and Tropical Legumes Projects. Schipmann et al. (2013) is an apt example. In Phase II, the priority should be on producing information on characteristic demand in early adoption and later varietal diffusion studies to update the existing trait profiles. At the start of Phase II, the existing information could be synthesized to identify any glaring gaps or incongruities in breeding and selection priorities. That synthesis would also serve as a benchmark in going forward.

Alternative Suppliers

The issue of alternative suppliers in general and for soybean in particular has been broached by the ISPC as a topic that warrants more description from the DCL in a Phase II Proposal. Alternative providers are relevant whenever a rigorous medium-term, priority-setting exercise is conducted. But, if discussed, the issue is rarely if ever quantified except via subjective scoring that is not very helpful (Alston and Pardey 1995).

When the research area is new product development, almost anyone, anywhere, at any time has the potential to become an alternative supplier. After attending a postharvest training course conducted by the International Potato Center, a local government employee in China quit his job and invented a new convenience breakfast food using dehydrated noodles made from sweet potato. He quickly became a millionaire; apart from diffused-light storage this was the biggest success story that CIP had achieved in more than two decades of postharvest research and capacity building.

Alternative suppliers for crop, land and water management practices include national and local public sector research institutes, NGOs, and farmers who have location-specific knowledge of problems and opportunities of dryland agriculture. In the late 1980s, World Vision came up with the practice of Farmer Managed Natural Regeneration (FMNR) that has added 15-20 million US$ to household income in Maradi in Niger (Haglund et al. 2011) and is spreading to countries of the Inland Sahel with zealous proselytizing from ICRAF. IER scientists in Mali together with colleagues from CIRAD were instrumental in developing *amenagement en courbes de niveau* (ACN), which translates roughly as 'ridge tillage' in southern Mali (Gigou 1996). ACN has also been tested in and extended to The Gambia, Senegal, and the Cameroons and had been actively supported by USAID's Soil Management CRSP (Kablan 2008). ACN has given favorable results that were validated in Mali in the USAID-funded Africa RISING Program (Birhanu et al. 2014). Assisted by lime as an input, farmers from the south of Brazil generated practices, tailored to acidic difficult-to-till soils, that were responsible for opening up the vast Cerrado area for cultivation on a sustainable basis. Farmers in Central India in Madhya Pradesh found ways to provide in-field drainage to rainy-season fallowed deep Vertiols so that soybean could descend from the hills onto the plains when its commercialization became profitable. They found means to cultivate these heavy soils without relying on ICRISAT's Vertisol Technology Options with Broad Beds and Furrows which ultimately and unexpectedly were adopted to sow irrigated summer groundnut.

The private sector can also chip in in specific circumstances. Seed priming and low-cost treatment with Syngenta Apron 42 TM has given substantial yield increases on the order of several hundred kgs per hectare in early experimental testing in on-farm trials in Niger and western Sudan. Testing and popularizing this seed treatment was one of the emphases in the Pearl Millet in Africa product line discussed later in this report.

Because germplasm is not widely adaptable and because its access is restricted, the universe of alternative suppliers is restricted for genetic improvement. Occasionally, a variety released in one region of the world can make its presence felt in another. The groundnut variety Fleur 11 from China appears to be one of those rare cases. It is gaining ground in farmers' fields in West Africa.

The term 'alternative suppliers' conjures up the image of competition, but strong complementarities can exist between non-CG institutes with a mandate in genetic improvement and CG Centers in the development and distribution of genetic materials. Strengthening not only NARS genetic improvement but also IITA's breeding capacity is the first objective in the Germplasm & Plant Breeding Program of the Soybean Innovation Lab funded by USAID. Another objective focuses on testing the adaptability of Latin American elite materials from Brazil and Argentina. The Peanut CRSP was heavily involved in the popularization and diffusion of disease-resistant, ICRISAT-bred ground varieties in East Africa (T. Williams, personal communication 2011). The INSTORMIL CRSP also played a role with ICRISAT in the development and dissemination of the hybrid Hageen-Dura in the Sudan and figures jointly in several releases in West Africa.

The participation of alternative suppliers is one of the distinguishing features of bean crop improvement in SSA. Multiple smaller institutional providers have added internationality to CIAT's primary role as a source of genetic materials for the generation of bean varietal output in ESA. These include the Bean and Cowpea CRSP in the USA, the Institute of Horticultural Plant Breeding (IVT) in the Netherlands, the Escuela Agricola Panamerica (EAP) in Honduras, the Centro Agronomico Tropical de Investigacion y Ensenanza (CATIE) in Costa Rica, the NVRS/Wellsbourne Project in the UK and the Tokachi Agricultural Experimental Station in Japan. Other institutional suppliers are a secondary source of materials for varietal release and have been very important to a handful of countries like Tanzania where improved varieties from the EAP lay claim to a sizable share of adopted area (Walker et al. 2015). Nonetheless, none of these institutional sources has generated, tested, and distributed materials on a widespread basis in the target countries for Phase II.

Of institutional alternative providers with a crop improvement mandate, INSTORMIL probably best fits the stereotype of a competitive alternative supplier. Because of its relatively small size, INSTORMIL's plant breeding activities have been focused on selected countries in Latin America and Sub-Saharan Africa. Several of the latter are targeted by the Dryland CRP in Phase II. Most of their collaborative work in SSA has focused on sorghum improvement. Prior to 2012 for which data are available (Heinrichs 2011 and Zeyeresus and Dalton 2012), INSTORMIL has been most active in sorghum improvement in Mali, Niger, Mozambique, and Zambia where more than five varieties have been released in each country since 1985. Work in the Sudan, Tanzania, and Ethiopia has been more episodic. INSTORMIL-related releases in pearl millet are not common.

INSTORMIL-related materials in sorghum are characterized by a higher share in adoption than their incidence in national releases in the DIIVA study carried out in 2009/10. In terms of area planted, INSTORMIL had several entries among the leading improved varieties in Mali, had the leading variety, a collaborative release with ICRISAT and INRAN, in Niger, and had two improved striga-resistant varieties that ranked 3rd and 4th in Tanzania (Ndjeunga and Mausch 2015). INSTORMIL's research partially offset and compensated for ICRISAT's overly aggressive pursuit of a breeding strategy focusing on shorter statured, photoperiod-insensitive materials in the 1970s, 1980s, and on into the 1990s in sorghum in West Africa (Walker 2015). In SSA between 1980-2011, only about 25% of national releases of improved sorghum cultivars were related to ICRISAT.

In relative terms across food crops, INSTORMIL is not the most important alternative supplier. CIRAD in France is. CIRAD and its precursor IRAT has played a large role in generating materials that have resulted in varietal change in several food crops, especially rice, in West Africa.

Other institutional suppliers play a proportionally larger role in contributing to varietal output in other crops in selected regions. The Honduras Foundation for Agricultural Research (FHIA) has supported the improvement of banana particularly in finding cultivars resistant to *Fusarium wilt* in the brewing, cooking, and dessert type of that crop in ESA. Most of the releases of improved clones in Uganda come directly from FHIA elite materials (Walker et al 2015). Between 1958 and 2010, the private sector – without participation from other institutions – was responsible for 56% of maize releases in ESA (De Groote et al. 2011). The private sector is well established in Kenya, Zambia, and Zimbabwe where hybrids dominate the national and the regional market. Increasingly, CIMMYT has adopted a more active posture in joint releases with the private sector, but it has a long way to go before it reaches the level of participation of ICRISAT's Hybrid Parents Research Consortium (HPRC) that focuses on disease resistance, drought and heat tolerance, and nutrient (Fe & Zn) density. About half of pearl millet hybrids released in India are derived from HPRC's inbred or restorer lines.

Turning to the specific case of soybean that was cited by the ISPC, the Soybean Innovation Lab (SIL) has been most active in selected target countries including Ghana, Mozambique, and Zambia. The Soybean Innovation Lab Germplasm & Plant Breeding research team is collaborating with the Syngenta Foundation for Sustainable Agriculture (SFSA) and the African Agricultural Technology Foundation to implement coordinated soybean variety tests across several countries in Africa (Soybean Innovation Lab 2015). Three regional tests in Africa were being conducted in 2015 in (1) Kenya, (2) Senegal and Mali, and (3) Malawi and Zimbabwe. SIL research partners at the Savanna Agricultural Research Institute (SARI) in Ghana, the International Institute for Tropical Agriculture (IITA) in Zambia and the Jimma Agricultural Research Center in Ethiopia all provided soybean lines for the evaluation of adaptability. As implied earlier, SIL's emphasis in SSA is characterized by its complementarity to IITA's crop improvement program on soybean.

Soybean also did not stand out in the DIIVA study as a crop that unduly benefitted from the presence of alternative suppliers in terms of output, outcomes, or impact. Soybean ranked 11th of 20 crops as its share of CGIAR-related varieties to total varietal releases since 1980 approached 50%. Soybean ranked 10th in the difference between area adopted in 2010 and its historical share of releases. That difference approached a positive 15% indicating that IITA-related varieties were proportionally more evident in farmers' fields than their incidence on national release lists.

Summing up, it is hard to make a strong case for divesting of crops or facets of the breeding agenda because of the supposed strength of competing suppliers in Phase II of a proposed DCL. Historically, the argument for reallocating research resources due to alternative suppliers is considerably more robust for banana and maize in East Africa and for rice in West Africa than for the dryland crops in SSA or in India. Of the alternative suppliers, the Innovation Labs in the U.S. are the ones that need to be closely linked to activities in Flagships 2 & 3 in the Dryland CRP. Giving the uncertainty of agricultural research, linking does not necessarily mean following the same strategy as some degree of competition is healthy. Unfortunately, given the current political reality in the United States, the Innovation Labs are likely to be strapped for operating budget in Phase II.

Target and Spillover Countries in Phase II

The 15 target and 18 spill-over countries that are proposed to receive spatial emphasis in Phase II appear to be well chosen in terms of what DCL can contribute to the global strategic objectives of poverty reduction, nutritional improvement, and environmental sustainability. Work was conducted in many of these 71 crop by target country combinations in Phase I (Table 1) (page 5). From the perspective of ICRISAT's mandate, the target countries do not represent a geographic limitation. Phase II focuses on many selected countries in SSA, on India, and on Morocco in North Africa. Spill-over countries are mostly located in North Africa, Central Asia, the Middle East, South Asia, and Southeast Asia with a few countries chosen in Latin America. Spillover outcomes are substantially more important in barley and beans than in the other 12 crops (Table 2) (page 5). Groundnut ranks first among target countries and third among spill-over countries in economic importance (Tables 1 and 2).

In Phase I, research in the Dryland Cereals CRP was not spread equally across all target countries as scientists wisely concentrated their efforts on a geographic subset ranging from 3-5 counties in most product lines. A similar focus on a restricted number of target countries is expected to pay dividends in Phase II especially if funding becomes limiting.

In the Grain Legumes CRP, a narrower focus on a few target countries was not as evident as it was in the Dryland Cereals CRP. To facilitate the transition to the need to focus attention on fewer countries it may be useful to add 2-3 spill-over countries that are intensive producers of beans and/or barley and that figured as targets in Phase I. Presently, beans and barley are poorly balanced with the bulk of their value of production in spillover countries. Because of its very small share in value of production, Zambia could be moved from the target to the spillover list and could be replaced by Rwanda for beans and Kazakhstan for barley.

Within the product lines, we should also see some shifts in geographic emphases at the margin and, in a few cases, substantial re-structuring appears to be necessary. Comments pertinent to the geographic reallocation of resources are made in the next section on product lines and their prospective technologies. Before discussing these specific points, we address three countries that warrant special consideration in Phase II.

The Sudan

Among the target countries, the Sudan appears to be the major omission in Phase I work, especially in Dryland Cereals. Testing faba bean germplasm for heat tolerance was an exception to the generalized lack of a collaborative research activity in the Sudan. (Indeed, the recent expansion of faba bean from a negligible area to slightly over 100,000 hectares is a story that needs to be told in terms of how it evolved, the production environment, and the characteristics of the producing households).

Sudan ranks third after India and Nigeria in terms of the share of value of production across all crops for the 15 target countries. Much of Sudan's importance is due to sorghum. Eight million hectares sown to sorghum makes Sudan the world's most extensive producer of the crop. Production at 5-6 million tonnes annually, in non-drought years, is similar to India's level and is only exceeded by Nigeria's output according to FAOSTAT, which also puts South Sudan's sorghum production at 0.75 million tonnes in 2014.

Both sorghum and pearl millet are staple food crops in The Sudan and South Sudan. In 2009-2013, sorghum's share in cereal consumption was estimated by FEWSNET at over 50%; pearl millet contributed 10%, and about 1/3rd was provided by wheat which is mainly imported. Sudan is unique in Sub-Saharan Africa in that the shares of maize and rice in national cereal consumption are each less than 5%. As was discussed above, high budgetary shares in consumption expenditure point to significant potential for very large outcomes for poverty alleviation and nutritional enhancement. Given these initial production and consumption conditions, the scope for making impact on Strategic Objectives 1 & 2 is greater in Sudan than in any other target country with the exception of Niger.

Collaboration between Sudan and ICRISAT has been episodic. Lack of intensity and continuity in research partnership is attributed primarily to prolonged conflict in Sudan and secondarily to sorghum's unique production conditions in the country. About 0.5 million hectares is in the irrigated sector with high yields and almost complete adoption of HYVs (Zereyesus and Dalton (2012). The bulk of area (4.0 million has) is mechanized and grown under rainfed conditions with moderate adoption of improved cultivars. Small farm households account for 2.0 million hectares with low levels of varietal change in rainfed conditions. Low productivity levels are endemic to both the rainfed mechanized and the small householder sub-sectors.

If prolonged conflict is resolved or even dampened, the CRP needs to allocate more resources to Sudan in the development of prospective sorghum and millet technologies. Estimated research intensities for sorghum- and pearl millet-producing countries in West Africa are typically 10-50% of those for maize. In the recently concluded DIIVA project, only the ARC in Sudan had made a research commitment for sorghum that rivals the research intensities found in maize-growing countries especially those in East Africa. Relative to others in SSA, the ARC is one of the stronger national programs.

Past collaboration has been productive. The best-known example is the popular sorghum hybrid Hageen Dura-1 which was the genetic output that was responsible for Gabisa Ejeta winning the World Food Prize in 2009. In terms of practical impact, Hageen Dura-1 is the most visible result of an ICRISAT-coordinated, multi-phase, country-focused UNDP-funded program that mainly supported millet improvement in Burkina Faso, Mali, Niger, Nigeria, Senegal, and Sudan in the late 1970s and early 1980s.

More recently, collaboration with The Sudan resulted in one of the first releases of enhanced cultivars with MAS and backcrossing. ("We do not have anything like this in wheat" (Tony Fisher, 2015, Personal Communication). Striga-resistant varieties in the genetic backgrounds of popular, but *Striga*-susceptible, improved sorghum varieties 'Tabat', 'Wad Ahmed' and 'AG8' were released for cultivation in Sudan in 2012, but the collaborative work began much earlier in 2004 with several partners in BMZ-funded projects and a competitive grant from ASARECA (ICRISAT 2012). Genotyping for the last generation of marker-assisted selection was completed at the BecA facility of the ILRI-Nairobi campus before the product lines could reach the required state of agronomic eliteness combined with high and stable levels of host plant resistance to *Striga hermonthica*. Standard variety trials in 2009-2011 (over three rainy seasons) at the Gezira, Damazine, Sinar, and Gedaref in Sudan led to release of the backcross lines that were Striga-resistant and agronomically superior to their parents.

Because of the methodological importance of this work, a high priority should be attached to ascertaining the fate of these enhanced recently released cultivars to determine constraints to adoption that inform about the applicability of MAS with backcrossing not only in sorghum but also in the other cereal and grain legume crops, e.g., the ongoing work in groundnut with TMV-2 and JL 24 (Yeri et al. 2014). *A priori*, MAS with backcrossing could be very relevant to leverage varietal change in groundnut which is characterized by the remarkable staying power of 'ruling' varieties.

Niger

Unlike Sudan, ICRISAT has made a large and sustained commitment to Niger since the establishment of the ICRISAT Sahelian Center (ISC) in 1983. With hindsight, the ISC was not a good fit for much of ICRISAT's mandate. The move to consolidate research in Mali is a welcome development because the needs of the higher potential Sudanian and Guinean Savannahs can be more effectively addressed.

Even though ICRISAT has diminished its presence in the ISC, the Phase I work on Dryland Cereals underscores the priority that the CRP attached to Niger. Five new pearl millet varieties were released, and a sizable quantity of seed was produced.

The Phase II CRP needs to stay the course in Niger because of the importance of agronomic and economic resiliency and the potential to generate large outcomes in Strategic Objectives 1 and 2. In other words, Niger's relative importance to the CRP is greater than the size of its population or its area of pearl millet, sorghum, and cowpea production. As discussed earlier, Niger's rural food consumption is the densest of any country in focus crops of the DCL CRP. Niger displays the most regionally homogeneous consumption pattern of any target country; all the major sub-regions rely heavily on either pearl millet or sorghum or both and on cowpea.

Niger has also needed drought relief on numerous occasions. Since 1900, 300 country-specific, drought-identified natural disasters have occurred in SSA. More than 400 million people have been affected. Analysis of the Emergency Events Database (EM-DAT) natural disaster database compiled by the Centre for Research on Epidemiology of Disasters (CRED) at the Catholic University of Louvain in Belgium confirms conventional thinking that the historical incidence and severity of drought in SSA is significantly greater in the more arid than in the wetter dryland zones. Based on the HarvestChoice database, about 50% of cultivated area in the Arid Tropics of SSA is in Niger.

Estimating the ratio of the cumulative number of persons affected to the national population in 2010 provides a simple aggregate index of the severity of drought over time. Among the target countries in SSA, the severity index ranges from 1.90 in Niger to 0.02 in Nigeria. Only one severe drought is recorded in the EM-DAT database for Nigeria; Niger has experienced 13 since 1900.

Niger is the poster country for drought-induced production shortfalls in SSA. Human suffering caused by drought is visible, palpable, and engenders an institutional response. Despite several agricultural successes (Mortimore et al. 2001 and Reij et al. 2009), Niger has had to avail itself of large-scale humanitarian assistance four times since 2000 in response to recurring droughts and plagues of locusts (rangeland grasshoppers). In other dryland regions of Africa, new varieties and crop management practices can contribute to intensification that leads to marketed surplus, lower prices, and enhanced food security. In those regions, generally droughts are more intermittent and less severe, strains of downy mildew infesting cereals are less virulent, insects do not attack cowpea with the ferocity of Maruca (pod borer), and sandstorms and plagues of locusts are rare occurrences. In Niger, productivity gains are still important and possible, but productive agricultural research is likely to have more leverage on increasing risk benefits and reducing vulnerability than on intensification (van Ginkel et al. 2013).

Agricultural research is not a perfect substitute for disaster relief that diminishes funds for resources for agricultural development including agricultural research. But disaster relief has taken on a new dimension with the increased migration of young West African men to Europe. Rightly or wrongly, drought partially induced by climatic change is believed to be an important contributing factor to the upward trend in the flow of potential migrants (Friedman 2016). The youth bulge in labor force participation is one of the more visible so-called mega-trends occurring in West and Central Africa (Jayne et al. 2016). The stock of first-generation immigrants from Africa and the Middle East to the EU is projected to nearly triple in this coming generation (Hanson and McIntosh 2016).

Myanmar

Myanmar ranks second among spillover countries in value of production in Table 2 (page 5). Among developing countries, Myanmar has become a pulse powerhouse. It produces 4-5 million tonnes of pulses annually, mainly black gram, pigeonpea, mungbean, and chickpea. About one million tonnes are exported to India. In the past three years, the value of yearly exports has averaged about 750 million US$. Two thirds of the value of trade to India is derived from the export of black gram, the highest priced pulse that India imports. The other one third comes from pigeonpea, mung bean, and chickpea. Myanmar has a virtual monopoly over the trade in black gram as its exports account for over 99% of Indian imports. Myanmar also has the highest yields of pulses cultivated in Asia.

At 25%, Myanmar is characterized by the highest incidence of poverty among the ASEAN countries. The use of improved varieties is gradually increasing from a low base. Myanmar benefitted from ICRISAT's Asian Grain Legume Program (AGLN) in pigeonpea, chickpea, and groundnut in the 1980s, 1990s, and early 2000s. Myanmar is also the spillover country that is in a position to capitalize on hybrid pigeonpea that has given positive results in experimental station yield trials and on-farm tests. Adaptability is not surprising because Myanmar's monsoon rainfall regime is similar to peninsular India's.

Myanmar also has considerable to offer to the DCL CRP in Phase II, most topically in the extra early chickpea and lentil product line. Lessons could be learned on how it has succeeded in expanding pulses in rice fallows.

The Product Lines in Phase I: Implications for Phase II

Of the three Dryland CRPs, prospective technologies are most transparent in the Grain Legumes CRP where the product lines in Table 11 are largely synonymous with technological outputs. It is also easy to identify prospective technologies in the Dryland Cereals CRP. For example, improved cultivars in the Sudanian and Guinean Savannah, integrated Striga management, and microdosing fertilizer have loomed large in the first product line on Sorghum for West and Central Africa. Likewise, rainy-season, summer-season, drought-tolerant, forage, and high Fe hybrids figure prominently as five prospective technologies in the sixth product line on Pearl Millet for East Africa and South Asia which has focused almost entirely on India.

Prospective technologies with international public good characteristics are not as easy to identify in the Dryland Systems CRP where research was organized around five broad regions that featured an emphasis on sub-regional transects and/or geographic areas: West African Sahel and Dryland Savannas, North Africa and West Asia, Eastern and Southern Africa, Central Asia, and South Asia.

The 15 product lines in Table 11 for the Dryland Cereals and Grain Legumes CRPs would easily surpass minimum standards of International Public Goods. A few are relatively new and novel like finger millet in East Africa, herbicide and mechanization of chickpea and lentil in India, and even post-rainy season sorghum in India. Most are supported by two to four decades of so-called 'legacy' research. These have been extensively vetted, reviewed, and fine-tuned over time. That is not to say that there is limited room for improvement in allocating research resources within and across the 15 product lines in Table 11. Later in this section, we address specific issues and queries about each product line with potential implications for Phase II. But, first, we discuss what the Dryland Systems CRP can contribute to Phase II in terms of prospective technologies that warrant pursuing.

Table 11. Organization of the research portfolio by Dryland CRP in Phase 1

Dryland cereal	Grain legume	Dryland systems
Sorghum for West & Central Africa (Burkina Faso, Mali, Niger, and Nigeria)	Drought and low P tolerant bean, cowpea, and soybean	West African Sahel & Dry Savannahs (Niger, Nigeria, Ghana, Burkina Faso, and Mali)
Pearl Millet for Africa (Burkina Faso, Mali, Niger, Nigeria, and Senegal)	Heat-tolerant chickpea, common bean, faba bean, and lentil	North Africa & West Asia (Tunisia, Morocco, and Egypt)
Sorghum for East Africa (Ethiopia, Sudan, Tanzania, Mozambique, and Kenya)	Short-duration, drought-tolerant, aflatoxin-free groundnut	Eastern and Southern Africa (Kenya, Ethiopia, Malawi, and Mozambique)
Finger Millet for East & Southern Africa (Ethiopia, Kenya, Tanzania, and Uganda)	High nitrogen-fixing chickpea, bean, faba bean, and soybean	Central Asia (Turkmenistan, Uzbekistan, Kazakhstan, and Tajikistan)
Barley for Africa and Asia (Ethiopia, India, Iran, Kazakhthan, Morrocco, and Turkey)	Insect-smart cowpea, chickpea, and pigeonpea production systems	South Asia (Pakistan and India (Rajasthan, Andhra Pradesh, and Karnataka))
Pearl Millet Hybrids for East Africa (Sudan, Tanzania, and Uganda) and South Asia (India)	Extra early chickpea and lentil varieties	
Post-rainy Season Sorghum in South Asia (India)	Herbicide-tolerant, machine harvestable chickpea, faba bean, and lentil varieties	
	Pigeonpea hybrids and management practices	

Prospective technologies in the Dryland Systems CRP

In contrast to the Dryland Cereal and Grain Legume CRPs, Dryland Systems' contribution to Phase II appears to be attenuated for the following reasons. First, ICARDA, the implementing CG Center, did not have much earlier research in resource management to draw on in Sub-Saharan Africa which encompasses the vast majority of the target countries in Phase II. For all intents and purposes, its legacy research was in two of the five regions, North Africa & West Asia and Central Asia, in its natural resource management program that dates from the mid-1970s. Morocco is the only Phase II target country in those two regions. ICARDA had to rely heavily on multiple partners with varying research agendas to satisfy demands for work in the Sub-Saharan African and South Asian Regions.

Secondly, the rate of return on investment in natural resource management has been low to negative in the CGIAR. Positive ex-post impact assessments of natural resource management technologies are conspicuous for their absence on the SPIA website. There are some success stories to report, most notably, the innovation in and deployment of minimum tillage techniques facilitating the earlier planting of wheat in the extensive rice-wheat cropping system in India. Early gains from the Rice-Wheat Systemswide Initiative in the Punjab and Haryana have been consolidated and extended to East India via the USAID-funded CSISA Project.

Location specificity is the bugaboo of natural resource management. The rice-wheat cropping system in South Asia is unique its agroclimatic and edaphic homogeneity. Natural resource management technologies become more location specific as they become more integrated. As location specificity narrows, the potential for generating international public goods rapidly diminishes and institutional attribution becomes increasingly implausible.

Thirdly, the Dryland Systems CRP worked broadly on irrigated, rainfed, and agro-pastoral systems in dryland agriculture. The absence of boundaries across its geographic area of operation leads to fuzziness in defining prospective technologies. Annual reports that feature indicators of achievement for donors and not research results for scientists are not conducive to clarifying outputs attributable to a program.

Lastly, and perhaps, most importantly, the Dryland CRP did not have sufficient time to mature. Some of the regional emphases in Table 1 placed a premium on a long-term horizon for R&D to translate into practical results. For example, the South Asian region features some of the most difficult production circumstances imaginable with the choice of sites in Bikaner and Jaisalmer districts in Rajasthan and Anantapur in Andhra Pradesh. Making progress in these adverse conditions requires a 15-20 year planning horizon.

Excessive planning occupied the attention of research management in the formation and early years of the CRP and probably contributed to instability in research personnel. Such planning requirements were not unique to the Drylands CRP, but “15 must haves” from the Science Council placed an onerous burden on management when a program was starting largely from scratch (Merrey 2016). Excessive planning, based on a vacuous evaluation literature that has rarely if ever been empirically tested, quickly reaches the point of diminishing returns for agricultural research which is not a manufacturing process with deterministic outputs, but is stochastic and characterized by uncertain returns. Instability in W1/W2 funding in 2014-16 also has taken a toll on the program.

Tightening operating funds translated into diminishing research outputs in one of the smallest – from a budgetary perspective—CRPs (Merrey et al. 2015). Reviewers complained that they only had a bare-bones version of the program to evaluate.

In going forward in Phase II, the Grain Legumes and Dryland Cereals CRP should undertake a rapid evaluation to determine if there are any promising technologies that have wider adaptability and that could be considered as potential project lines from the work undertaken in the two regions in Sub-Saharan Africa by the Dryland CRP. In this way, the null hypothesis that the Dryland CRP does not have much to contribute can be tested in a more formal manner. The value of working in transects in West and East Africa is a priority issue for such an assessment.

Prospective Technologies in the Dryland Cereal CRP

Below we comment briefly on the results of the Phase I Dryland Cereals CRP with an eye towards priority setting and resource allocation in a consolidated CRP in Phase II. Our commentary draws on the presentations at the final results workshop and the CRP Commissioned External Evaluation of the CGIAR Research Program on Dryland Cereals that was published early in 2016.

Sorghum for West and Central Africa. In Phase I, this product line focused on three countries: Mali, Burkina Faso, and Nigeria. The most notable prospective technologies are the new Guinean Hybrids, microdosing, and Integrated Striga Management (Toure 2016).

The Guinean Hybrids that date from 2000 with the selection of female parents are an emerging success story that is increasingly well documented. In an innovative *ex-ante* assessment (Kergna et al. 2016), all (2,430) sorghum-growing households were surveyed in 58 villages with early access to improved sorghum varieties and to the recently produced Guinean Hybrids in two Malian regions. Areas planted to improved sorghum types increased from 2009-2013, more rapidly for improved variety types than for local types, and most rapidly for hybrids, although hybrid growers still represented a minority in these early stages of testing and acceptance. The analysis clearly shows the benefits of on-farm selection and locally-based seed multiplication with an emphasis on hybrids vis-à-vis state-managed research and development.

Subsequent adoption research based on the same survey found that the impact of hybrids on yields was large and significant, positively affecting household dietary diversity and contributing to a greater share of the harvest sold (Smale et al. 2016a). However, use of hybrids, as well as improved varieties, is associated with a shift toward consumption of other cereals.

Using the same database, Smale et al. (2016b) document the discriminatory effects of Mali's current fertilizer subsidy on sorghum relative to maize, which is favored by the policy. Methodologically, these three inquiries demonstrate the benefits of investing in a multi-purpose database.

The emerging success story with the Guinean hybrids will still require considerable nurturing in Phase II in Mali. As described earlier, Ndjeunga et al. (2011) provides a cautionary tale. Following a spate of varietal releases coupled with an ambitious extension program in the late 1990s in northern Nigeria, analysis of survey results suggested that the improved sorghum cultivars did not possess sufficient agronomic and economic advantages to leverage sustained adoption. By 2009/10, many households had disadopted improved varieties that they had initially accepted. A positive *ex-post* impact assessment could not be conducted.

Having said that, sorghum in Burkina Faso should receive more emphasis in Phase II to ensure that more farmers there have access to spill-over benefits from the Malian experience with the new Guinean Hybrids. Historically, Mali has released more improved cultivars than any other country in West and Central Africa. In Phase I, 33 of the 36 releases took place in Mali. Burkina Faso has a good track record in varietal change and productivity growth in maize and rice, which makes the apparent lack of progress in the Burkinabe national program in sorghum all the more puzzling (Walker and Alwang 2015).

Pearl Millet for Africa. Burkina Faso, Mali, Niger, Nigeria, and Senegal were the focus countries in Phase I (Ba 2016). They account for the bulk of pearl millet production in SSA.

By 2022, 'Pearl Millet in Africa' seeks to increase production in the five focus countries by 3.5 million tons. Based on production levels in 2008-10, this target is equivalent to a 25% increase. A 25% increase in production in 10 years is consistent with the overall goals set for product lines in the Phase I Dryland Cereals and Grain Legumes CRPs. But it is equivalent to setting a very high bar. Results from the DIIVA Project on the adoption and diffusion of improved varieties in SSA can help to put the target in context (Walker and Alwang 2015). About 3600 improved varieties were released between 1980-2010 in 20 food crops. Of these, the most extensively grown improved cultivar was the pearl millet variety SOSAT C-88, which in 2009-2010 was sown on slightly over 1.0 million hectares in Nigeria, Mali, and Burkina Faso. Assuming an on-farm yield gain of 200 kgs/ha, the target of a 25% increase in production would be equivalent to replicating the success of SOSAT C-88 15-20 times from 2012-2022. The product line has other weapons in its arsenal other than varietal change, but believing that a high-profile success story like SOSAT C-88 could be repeated 15-20 times in a 10-year period stretches the limits of credibility. More realistic targets should be established in Phase II.

The prospective technologies are similar to those for the previous product line on sorghum in West Africa. Additionally, downy mildew resistance and control of head miner are important priorities. The generation of new OPVs and the development of hybrids was a major area of activity. OPVs were emphasized in Phase I; however, the prospects for hybrids look bright. Microdosing with DAP, NPK, and manure, a seed treatment with Sygenta's Apron 42, and biocontol of head miner with a newly introduced parasitic wasp figured prominently in soil fertility, crop, and pest management.

Fourteen new varieties and one hybrid were released in Niger (7), Nigeria (2), and Mali (6). Points for seed sale were established in 50 villages in 2016; 25,000 minibags of seed of 200 grams were sold in 40 villages. The releases in Niger are especially important because they are the first since 1997. In the early 2000s, the pipeline of new releases dried up. Releasing seven varieties in Niger during Phase I was no small achievement. Likewise, the two releases in Nigeria are noteworthy because the country had only released three varieties from 1987-2010. The ratio of the size of production to the number of varieties released from 1980-2010 was higher for pearl millet in Nigeria than for any other crop country combination in the 20 crop – 30 country DIIVA Project.

Development activities were concentrated in Niger where new varietal adoption in Phase I approached 900,000 hectares. Among six management practices tested and demonstrated, demand for microdosing was strong. About twice as many farmers had accepted microdosing (19%) as had initially adopted new varieties (10%).

Activities in Senegal were reported as very limited, and outputs in Burkina Faso were not that visible in the Phase I results. After a hiatus of more than three decades, Senegal released five varieties in 2011. It would be interesting to see how they are faring with a rapid rural appraisal if early acceptance studies have yet to be carried out.

As argued earlier, the excellent progress in Niger should be consolidated in Phase II. Niger is not included in Phase II in Project HOPE. ICRISAT needs to find ways through other sources of bilateral funding to redress that omission.

Hybrids warrant greater priority in Phase II. From the perspective of access to research materials, mainly parental and restorer lines, ICRISAT's Hybrid Parents Research Consortium (HPRC) in India is a potential institutional model for West Africa. Both the public sector and the private sector have benefitted from this partnership that has generated more than 70 ICRISAT-related pearl millet and sorghum hybrids produced by seed companies since 2000 (ICRISAT 2013).

The next step is the demonstration that these hybrids are commercially viable. Where the private sector is not presently active, farmer groups and cooperatives are being trained in commercial production as demonstrated in the Sorghum in West Africa Product Line.

The road to improving the availability of coarse cereal hybrids in West Africa is long and potentially arduous, with formidable technical and policy obstacles along the way. In particular, prospective pearl millet hybrids should be endowed with durable sources of downy mildew resistance. Public sector policy requires critical regulatory attention on key issues such as enforcement of truthfully labeled seed in a generalized background of liberalization.

Guidance is available on steps to pursue from the experiences of the overwhelming acceptance of pearl millet and sorghum hybrids in India and maize hybrids in southern Africa. Moreover, recent initiatives, such as the Alliance for a Green Revolution in Africa (AGRA), can shorten the trip to a maturing hybrid industry by strengthening agro-dealer networks. As experiences with cereal hybrids in India and southern Africa have vividly illustrated, a maturing hybrid seed industry featuring public- and private-sector partnership is a cost-effective way to fill sub-national profiles with many diverse genotypes that are adapted to the more localized agro-climatic, edaphic, and market demands of farmers.

Sorghum for East Africa. As in West Africa, drought-tolerance and Striga resistance featured prominently in this product line. Research was also conducted on leaf diseases, sorghum/legume intercropping systems, and on new uses for the crop (Manyasa 2016). Ethiopia, Sudan, Tanzania, Mozambique, and Kenya were selected as the priority countries in Phase I.

This product line also benefitted from exhaustive priority setting. A research cum training exercise compared expected benefits and costs in sorghum improvement in Ethiopia, Kenya, and Tanzania (Gierend et al. 2014a, 2014b, and 2014c). *Ex-ante* technology assessment was also conducted at the regional scale with IFPRI's IMPACT Model (Orr and Gierend 2016). Demand for the crop was comprehensively analyzed by blending national consumption expenditure surveys with FAOSTAT data for Ethiopia, Kenya, Tanzania, and Uganda (Gierend and

Orr 2015). The three sorghum product lines from West and Central Africa, East and Southern Africa, and India were also assessed in an integrated assessment of potential for spillovers drawing on methods work from ACIAR (Kumara Charyulu et al. 2016) that is discussed more fully in the next section.

Despite what seemed to be a low level of investment in critical mass especially in direct IRS participation, this product line was impressive in terms of varietal releases. Four hybrids were released in Ethiopia. Hybrids were also released with private-sector participation in Kenya and Tanzania. Improved OPVs were registered in Ethiopia, Kenya, South Sudan, and Tanzania.

In going forward to Phase II, this product line is the one that is most in need of re-structuring. The bulk of the work in Phase I took place in Kenya and Tanzania and to a lesser extent in Ethiopia. In Phase II, geographic emphasis needs to shift more fully to Ethiopia and to Sudan. It is questionable that this change in geographic emphasis can be successfully accommodated by siting staff in the regional office in Nairobi. Directly placing 1-2 IRS in either Sudan or Ethiopia would seem to be necessary.

Several mutually reinforcing considerations point to the need to readdress the regional allocation of resources in this product line. The national shares of rural food consumption expenditure for sorghum in Kenya, Tanzania, and Uganda vary from about 1-3% (Gierend and Orr 2015). The shares are so low that it is almost impossible to envisage marked positive outcomes for poverty alleviation and/or nutritional enhancement. Moreover, urbanization is accompanied by a sharp fall in consumption. In the FAOSTAT data or in large-scale national surveys in Tanzania, a 10:1 production ratio maize:sorghum prevails. There are only 1-2 smaller subregions in Tanzania where maize is not the dominant cereal.

Although not included in the Gierend and Orr analysis, the same findings would most likely apply to Mozambique where bird damage is a severe constraint to production especially for photoperiod-insensitive improved cultivars (Tsusaka 2015). ICRISAT spent a lot effort in developing high-tannin sorghums for East and Southern Africa in response to bird damage, but apparently those materials have not penetrated into farmers' fields. INSTORMIL also allocated considerable effort to Mozambique in the early 2000s without much to show for that investment (Heinrichs 2011). Maize is the dominant coarse cereal in all ten provinces of Mozambique.

In contrast, Ethiopia was characterized by a 9% share of consumption expenditure, a level that is similar to the estimate in Table 10 for Nigeria in West Africa (Gierend and Orr 2015). A 9% share suggests sufficient scope to make substantial progress on Strategic Objectives 1 & 2. As argued earlier, the relative value of sorghum in rural consumption expenditure should be significantly higher in the Sudan where it is the main staple and does not face competition from maize.

Gierend and Orr (2015) point out that the estimates from the national surveys of consumption expenditure in Ethiopia lead to a few very counterintuitive findings, such as a substantial increase in the per capita intake of sorghum in the most recent survey, but the comparative evidence is overwhelming that demand for the crop is of a higher order of magnitude than in the other Phase I target countries in ESA with the exception of The Sudan. Moreover, urbanization is not accompanied by a steep fall in per capita consumption. Teff, sorghum, and millet, but not maize, are used to make *injerta*, the staple cereal-based food in Ethiopia (Gierend and Orr 2015).

Addressing the prospects for technological change, Gierend et al. (2014c and 2014b) find that the rate of return on investing in sorghum crop improvement is higher in Tanzania than in Ethiopia. Given the aforementioned results on consumption and the substantially larger sorghum area and base-level production in Ethiopia, the production prospects for sorghum have to be considerably brighter in Tanzania than in Ethiopia for this finding to obtain. This does not appear to be the case. A thorough economic evaluation suggests that the HOPE Project in Phase I did increase target farmers' awareness of improved cultivars and was responsible for small gains in adoption in Tanzania, but these statistically significant differences did not translate into any other outcomes and impacts (Orr and Muange 2015). Motivated by food security, target farmers in Central Tanzania were somewhat more likely to adopt earlier-maturing improved OPVs than the control group.

Rainfall is highly uncertain at the start of the planting season in Dodoma in Central Tanzania where sorghum attains some importance. Many farmers will replant maize several times during the season in the hope of making a crop. Replanting maize instead of sorghum or millet would not be cataloged as climatically 'smart', but the preference for maize is marked. Moreover, sunflower is now ubiquitous in Dodoma District, so much so, that its growing area is likely to exceed maize. Although sunflower is grown extensively with relatively few resources, scarce funds will be destined for intensifying crop management on the cash crop than for micro-dosing fertilizer or constructing planting basins for the food crop. Summing up, the prospects for intensifying sorghum production in Dodoma are bleak.

Relative to its value of production, ICRISAT has also invested heavily in regional sorghum and millet crop improvement SADCC with a USAID award that spanned almost two decades. Tanzania was one of the recipient countries. Factoring in international expenditures, the research intensities on sorghum improvement in Tanzania would most likely be among the highest in sub-Saharan Africa over the three decades. Yet, success has not been persuasively documented.

Methodologically, *ex-ante* assessment of technology cannot be based primarily on expert estimates especially from specialists in competing countries, prospective technologies, or areas of endeavor. Such estimates should be revised in a Delphi process that features input from general agriculturalists and other people knowledgeable about the relevant production circumstances. Broader participation, which in the past has been derogatorily called "mediocrity of the masses" by experts, is preferred.

Food security also looms large as the primary reason for cropping sorghum in Ethiopia; however, its consumption and production characteristics make it a substantially sounder R&D investment in sorghum crop improvement than Tanzania where the HOPE Project is continuing into Phase II. Unfortunately, business-as-usual in Tanzania is unlikely to lead to measurable progress (Orr and Muange 2015).

Finger Millet for East and Southern Africa. The countries of activity for finger millet overlap for the most part with those for the sorghum product line discussed above. They are Ethiopia, Kenya, Tanzania, and Uganda (Ojulong 2016). Based on germplasm stratification, the four countries correspond to two mega-environments, Ethiopia is in one and Uganda, Kenya, and Tanzania are in the other.

The overarching goal is an increase in production of 0.4 million tonnes in Ethiopia, Uganda, and Tanzania by 2022. The production constraints are similar to those for sorghum and millet in the Product Lines described above. Unlike pearl millet and sorghum, production of finger millet can be quite labor intensive. Blast also exacts a toll on production. Improved Striga management and microdosing fertilizer are synonymous with R&D in crop management.

Like the Dryland Cereals PLs, Finger millet for ESA is a complete crop improvement program that spans germplasm characterization to post-harvest handling and includes gender mainstreaming and capacity building. The scientific team is small in numbers, but quite large relative to the economic importance of the crop. Only two bilateral projects supported Finger millet for ESA but one of these was Project HOPE which provided stability for medium-term R&D. Finger millet is also in Phase II of Project HOPE in selected countries in ESA.

With relatively little funding, the PL has accomplished a lot. Seventeen varieties were released in the four target countries. Two with contrasting traits were released in three countries each. U15 is early maturing, has wide adaptation, good color and desirable-shaped heads, and is tolerant to blast and Striga (Ojulong 2016). P224 is a more commercial cultivar with big heads and is responsive to higher input use. Striga management features the use of trap cropping with a leguminous species. Microdosing using the equivalent of 20 kgs of N substantially increased yield and hastened maturity. Use of machine threshing was validated and promoted. Gender preferences for end uses is important in varietal development. Men's participation in weeding, harvesting, and threshing increases if appropriate technologies are introduced.

Finger millet was well-supported by socioeconomics research in Phase I. Consumer surveys in Kenya and Tanzania suggest that the demand for finger millet is higher than for sorghum especially in urban areas (Schipmann-Schwarze et al. 2013). Demand for finger millet for flour is strong in Kenya and Uganda among processing companies (Schipmann-Schwarze et al. 2015). Among interviewed firms, turnover was higher for finger millet than for other cereals except for maize and possibly wheat.

These studies and the results of Phase I research suggest that finger millet has a brighter future than either sorghum or pearl millet in Kenya, Tanzania, and Uganda in ESA. Allocating more resources to finger millet R&D among the three mandated ICRISAT-mandated cereals in Kenya, Tanzania, and Uganda is a logical outcome of these comparative findings on greater progress on supply and on stronger demand for the crop.

Barley for Africa and Asia. The target countries in Phase I are Ethiopia, India, Iran, Kazakhstan, Morocco, and Turkey. Baseline surveys were carried out in Ethiopia, India, and Morocco that are the priority targets for Phase II and represent the focal countries for spill-over effects in East Africa, South Asia, and North Africa. For the five dryland cereal product lines that focus on multiple countries, barley for Africa and Asia has the most complete coverage.

This product line also has a relatively large critical mass to move the research agenda forward in Phase II. Twenty-six new barley cultivars were released in Phase I including five in Ethiopia, three in India, and two in Morocco (Verma 2016). Like the other dryland cereals, drought is the major abiotic stress; salinity tolerance is also important in South Asia. Barley is plagued by multiple diseases; resistances to several foliar diseases is one of the cornerstones of the research program.

Barley will continue to bring a fresh perspective to the Phase II CRP. Advanced Research Institutes contribute heavily to this product line in multiple ways. Its seed research seems to be more applied than that of the other PLs that are oriented more directly to development. In Morocco, more effective utilization of existing seed policy offers an opportunity to improve seed availability especially for malting barley. Like the rice-wheat based cropping system on the Indo-Gangetic Plain, minimum/zero tillage technologies have been used with good results to advance the planting date of barley in prospective rice-barley sequential cropping systems in South Asia.

Even with a relatively large number of scientists, members of the PL acknowledge that they may be spread too thin to cover all the bases proposed in the five Flagship Projects. Research on post-harvest and crop management may fall short of expectations in Phase II.

Research support in social science appeared to be very thin on the ground in Phase I. As the research leader recognizes, impact assessment is an area that requires strengthening in Phase II. Miscal-21, the leading improved barley cultivar in Ethiopia, would be an interesting case study. M-21 came from ICARDA's program in Mexico. It consistently performed better than plant breeders' expectations in the DIIVA Project (Yigezu et al. 2015). Results from community and household surveys suggest that it has widespread adaptability and has already had a national impact on the production of malting barley.

Pearl Millet Hybrids for India and East Africa. This product line's R&D is heavily concentrated in India. In the past, the research area it embodies has been one of ICRISAT's most fruitful investments.

Justification for an emphasis on cereal hybrids is queried in the ISPC commentary. Once commercialization of hybrids becomes profitable, the economic incentives should be sufficiently attractive for the private sector to invest in hybrid development. Public sector research diminishes and re-orients itself to more fundamental investigations to support private sector research. Expenditure on public-sector research should not crowd out private-sector investment. Alternatively, the public-sector could focus on improved OPVs that are characterized by negligible incentives for private sector investment.

It is relatively easy to come up with a persuasive response to this conventional query from economists. First, hybrids have always been preferred by users in rainy season production of sorghum and millet. Hybrids became a reality in India in the mid-1960s about the time of the introduction of the semi-dwarf wheat and rice varieties. Since then, about an equal number of hybrids and improved OPVs have been released both nationally and at the state level (Kumara Charyulu et al. 2014). Historically, the leading varietal types in area planted were sorghum hybrids from the public sector and pearl millet hybrids from the private sector. Several improved sorghum varieties and one or two improved pearl millet OPVs, such as ICRISAT's WC-C75, were popular for a relatively short time span since 1964, but, in general, farmers have strongly preferred hybrids over improved varieties.

Their adoption in the monsoon season has fueled considerable growth in yield over the past five decades, and they are widely regarded as success stories in dryland agricultural research (Pray and Nagarajan 2009).

Secondly and more recently, pearl millet hybrids have penetrated into Rajasthan, the largest producing State in India with production conditions remarkably similar to the harsh southern Sahelian Zone in West Africa. Results from a large survey of 2,144 households suggested that over half of the pearl millet-growing area in Rajasthan is planted to improved materials, mostly hybrids, in conditions of smallholder subsistence agriculture. From their seed packaging, about 50 different hybrids were identified in the survey (Asare-Marfo et al. 2013). Some of the hybrids were prized for their superior grain yields; others were planted for their perceived excellence in fodder production.

The fact that numerous hybrids are being widely grown in the sandy soils of the arid tropics of Rajasthan rejects conventional wisdom that hybrids would not be able to compete with traditional varieties in such marginal production circumstances. This story is all the more compelling because the environment for pearl millet has steadily degraded over time as maize and other crops have pushed pearl millet into areas with more low and erratic rainfall regimes (Walker 2009). In particular, maize has replaced millet in the wetter parts of Eastern Rajasthan. In the mid-1960s, area-weighted, mean annual rainfall in the major millet-producing districts was 900 mm in peninsular India and Rajasthan. By the early 2000s, that same rainfall estimate had declined to 600 mm in the 40-50 most important producing districts. Long-term average rainfall has not declined in these districts. The composition of districts has changed. Millet is increasingly grown in the lower rainfall districts. No other cereal competes with pearl millet in these marginal rainy-season environments of limited production potential. Ceteris paribus, well-adapted hybrids are more resilient than well-adapted OPVs in these sub-regions where pearl millet has stood the test of time.

Thirdly, more fundamental research is carried out in this product line that complements private-sector investment. This complementarity underlies the rationale for the aforementioned Hybrid Parents Research Consortium (HPRC). The complementary nature of upstream research is reflected in the principal outcomes of enhanced genetic and cytoplasmic diversity of hybrid parents coupled with disease resistance, and increasing availability of hybrid parents for adaptation to drought, flowering stage heat stress, and salinity-affected environments (Gupta 2016). Disease resistance commands considerable attention. Blast has emerged as a new disease of economic importance.

Both traits and pearl millet cropping systems have been prioritized in terms of research investment (Jayalekha et al. 2016). Priority tolerances embrace blast, downy mildew, rust, lodging, and drought. The stay-green and dual-purpose traits are accorded a lower level of priority. The ranking of research domains in descending order is: (1) rainy season hybrids, (2) summer season hybrids, (3) hybrids for drought prone areas, (4) exclusive forage hybrids, and (5) high-Fe grain hybrids. The quantification in priority setting within this product line is laudable and establishes a valuable benchmark in going forward to Phase II. A simple feedback survey appears to have been a cost-effective vehicle to elicit information in this consultation process.

Lastly, the results of an independent farmer survey are also reported in Gupta (2016) for three States. HPRC-related hybrids were clearly superior in both grain and fodder in Rajasthan and Uttar Pradesh to non-HPRC hybrids. They also were characterized by higher production of grain and fodder in Gujarat but the differences were not as marked as in the other two states. A more systematic examination that builds on the results of this study could be an interesting and relevant exercise for *ex-post* impact assessment.

In Phase I, this product line had more outputs than most. The pearl millet genome was sequenced; 20 hybrids, based on HPRC materials, were released in the private sector; and one high-Fe grain hybrid was released with the A4N CRP. Dhanashakti, which was commercialized in 2012 in Maharasthra, presently occupies about 50,000 hectares in farmers' fields (Sivasankar 2016a).

Additionally, the variability in the rancidity profile of select commercial pearl millet varieties, hybrids, and hybrid parents was determined. This is one of the few linkages between crop genetics research per se and the post-harvest area that has tended to focus on value chains and new product development. The LeasyScan Platform, a novel 3-D technology, was developed to improve the phenotyping of traits, such as leaf area and transpiration, that are closely related to drought tolerance specific to three major agro-ecological zones of this production line.

In Phase II, the concentrated focus on India should continue. Pearl millet in the mostly Desert agro-ecology of western Sudan warrants some attention, but that research would be better supplied via the generalized pearl millet product line for Africa that was described earlier. With the exceptions of Sudan and Namibia, there is no evidence that pearl millet's share in food consumption expenditure nationally or even sub-regionally exceeds 1.0% in ESA.

Results from the comprehensive priority setting exercise facilitated by technical support from ACIAR are informative for regional resource allocation (Nedumaran et al. 2014). Expected benefits from an assumed 10% decline in the cost of production from technological change are heavily concentrated in India and in WCA. Total benefit in India is about 30 times and in WCA about 15-20 times higher than the comparable estimate for ESA where benefits accrue mainly to millet growers in the warm tropical subhumid production domain with a growing season longer than 150 days. Most of the millet in this agroecology is finger millet. As alluded to in Tables 3 and 4 (page 8), some of this area could be too wet to be considered dryland. The remaining benefits in the other production domains of potential interest to the DCL in Phase II are widely dispersed. Without considering spillovers, total net present value ranges from 0.7-2.5 million dollars in the remaining six production domains of relevance in ESA. For an ex ante assessment, these are very small sums for technological change equivalent to a 10% shift in the supply curve. Since 2000, only four ICRISAT-related pearl millet varieties have been released in ESA. The above leads one to the conclusion that pearl millet in East Africa is not a priority for the DCL in Phase II.

For supportive social science research, a follow-up study on the Fe-dense cultivar, Dhanashakti, is a priority. It is one of the first biofortified varieties commercialized in South Asia where iron deficiencies are common. A genetic gain of only 9-10% in iron content does not sound substantial or sufficient to leverage a qualitative difference in the attainment of threshold RDAs, but a recent RCT shows that among children who were iron deficient at baseline, those who received Fe-Pearl Millet were 1.64 times more likely to become iron replete by 6 months than were those receiving the Control-Pearl Millet (Finkelstein 2015). Assessing users' perceptions of the strengths and weaknesses of Dhanashatki relative to other reigning hybrids in Maharasthra should be one of the key parts of such as study. Specifically, are there any perceived sharp trade-offs between Fe denseness and other agronomically and economically important traits?

Postrainy Season Sorghum for India. Postrainy season sorghum is produced in one of the most challenging environments for intensification in dryland agriculture. The vertisols on which sorghum is sole-cropped can be deep and fertile. Grain quality is good to excellent because filling takes place in the cooler dry season when the incidence of disease, insect, and bird damage to panicles is not of agronomic or economic significance. Terminal drought stress at harvest is the binding constraint that limits productivity to about 600 kgs per ha. No other crop can compete with sorghum in biomass production in these receding moisture conditions.

In spite of limited technical change in the past, *rabi jowar* is still the most important cropping system for several million rural households in western Maharasthra and northern Karnataka. Historically, postrainy season sorghum did not receive as much emphasis in ICRISAT's sorghum crop improvement program as its economic importance warranted. Two reasons can be cited for this relative neglect: (1) the technical infeasibility in leveraging increased productivity in a system that is always characterized by terminal drought stress and (2) the potential for spill-over benefits is negligible and confined to small black-soil areas in Ethiopia.

Increasing on-farm postrainy sorghum yields by 34% by 2022 is the overall goal. This implies a linear growth rate of over 3.0% per annum which is a herculean task, but, in absolute terms of two to three hundred kgs per hectare, this objective becomes more doable.

Equal importance attached to grain and fodder adequately reflects market demand for the crop as a food grain and as livestock feed with the same shares in value of production. Drought is the dominant abiotic stress, shootfly the main pest, and charcoal rot the principal disease. The priority traits of drought tolerance (with some level of cold tolerance at flowering), shootfly resistance, and charcoal rot resistance convey a sense of timelessness that one feels on viewing cars and buildings in Havana today. An emphasis on high Fe and Zn varieties is newer in the late adolescent stage and is broadly shared with other crops in the DCL. Given fluctuations in the time of sowing, photoperiod sensitive varieties represent a lower risk and more appropriate strategy than hybrids (Kumar 2016).

Wider row spacing, in-situ moisture conservation, seed treatment, and fertilizer application loom large in improved crop management. Of these, in-situ moisture conservation and inorganic fertilizer application require an investment in labor or cash or both. It is not likely that they will be accepted as readily as new varieties or seed treatments that imply minimal monetary outlays.

In Phase I, there appeared to be heavy emphasis on the D in R&D as much effort was expended in adaptive research and in ensuring that earlier released varieties and improved crop management practices were made known to farmers in two large sub-regions of Maharasthra.

Since 2009-10, this PL has benefitted over 45,000 farmers via Project HOPE and the Dryland Cereals CRP in on-farm tests of new varieties and crop management practices. Over six cropping seasons, mean grain and fodder yields have increased by 30-40% over local check, M35-1, an elite pureline cultivar that was released in colonial times. (M35-1 is one of the most dominant varieties in agricultural history: it is characterized by excellent grain quality and by its stability in both grain and fodder production). About 9,000 tonnes of seed will have been produced in Phase I sufficient to reach more than 0.5 million farmers. Early adoption of the new varieties is high in the project areas, especially in the Marathwada region. Yield has increased from 600 to 850 kgs per hectare.

Somewhat surprisingly, no new varieties appear to have been released from this PL in Phase I. This apparent lack of output probably stems from the difficulty of this dryland production environment and/or from an emphasis on on-farm research and demonstrations in Phase I with multiple partners. In Phase II, varietal output needs to figure more prominently in this Product Line. Fortunately, strategic research realized in Phase I should help in attaining more lasting varietal output (Sivasankar 2016a).

With regard to priority setting, a very specific *ex-ante* assessment was conducted on the value of the stay-green trait that is associated with drought tolerance (Lalith 2014). Later in Phase II, early acceptance of the improved varieties and management practices should be assessed in both the project and non-project areas to determine the spread, durability, and the sequential nature of adoption. Both Project HOPE and Tropical Legumes I, II, and III of the Bill & Melinda Gates Foundation have invested heavily in baseline surveys that permit a before-and-after comparison for the documentation of technological change.

Indeed, more baseline surveys have been conducted in the past 10 years than in the previous three decades in the CG Centers. The reviews of both the DCL and GL CRPs were fixated on the misperception that impact assessment could not take place because of a paucity of baseline surveys (University of Greenwich 2016 and University of Reading 2016). Well-conducted baseline surveys are almost always to some extent informative, but they are not a sine qua non for impact assessment. The confounding effects of the weather need to be controlled for in with-and-without comparisons (Walker et al. 2008). If anything, the heavy reliance on bilateral projects has led to an overinvestment in baseline surveys.

One recommendation of the DCL review team does resonate: where appropriate, incorporate longitudinal VDSA sites as venues for complementary socioeconomic inquiries (University of Greenwich 2016). In this case, quantifying the spread of these improved varieties and techniques to the VDSA villages in Solapur District would supplement the wider evaluation of the uptake and continuity of adoption in western Maharasthra. In the mid-1980s, when fertilizer application was tested in those villages, positive results were obtained from the trials, but adoption was not sustainable (Dvorak 1992).

Prospective Technologies in the Grain Legume CRP

Prospective technologies were most transparent in the Grain Legumes CRP where research was organized around the demand for specific characteristics that resulted in eight product lines involving seven crops. Among the reviews conducted in Phase I of all the CRPs, GL's was unusually detailed and addressed not only the process but also the substance of the work being conducted. The eight product lines were evaluated in a 48-page Appendix from the perspectives of relevance, efficiency, quality of science, effectiveness, impact, gender, capacity building, and partnerships (University of Reading 2016). Each product line was also graded on four criteria: (1) outputs, (2) impact, (3) environment, coordination, and capacity building, and (4) gender balance and sensitivity. Based on a maximum of 100, scores were assigned to each product line. The evaluation of the review team and the presentations at the review workshop in October 2016 figure significantly in the commentary that follows:

1. Drought and low P tolerant bean, cowpea, and soybean. This product line was the largest in Phase I accounting for $1/5^{th}$ of the GL CRP budget. PL II is largely synonymous with CIAT's bean and IITA's cowpea program. Soybean is not as visible as bean and cowpea.

In Phase I, the overriding challenge was to focus a diversified crop improvement program(s) on the interacting constraints of drought and low soil P. In Phase II, the emphasis will shift to a narrower geographic focus on only a few target countries. In Phase I, work took place in 18 countries for beans, 10 for cowpea, and 5 for soybean.

The output of released varieties and seed was prodigious: 134 abiotic and biotic stress tolerant bush bean varieties, 16 new varieties of cowpea, and 18 varieties of soybean released since 2010 in SSA (Beebe 2016). Most of the bean varieties were the outcome of PVS in East and Southern Africa. The cowpea releases are particularly noteworthy because their higher incidence in this recent 5-year period reverses stagnation in varietal output between 1990 and 2010 (Alene et al. 2015).

Bean seed made available to farmers approached 100,000 tonnes (Sivasankar 2016b). Sixteen thousand five hundred tonnes of cowpea and soybean seed were also produced. The PABRA network was viewed as exemplary in supporting the D side of the R&D mandate of PL1. Not surprisingly, this product line received the highest score for impact by the review team.

Although I have not surveyed the literature relevant to this product line, it seems to have been supported well during Phase I with regard to investigations related to priority setting. Those studies range from an *ex-ante* assessment of the value of drought tolerance in beans in Global Futures to the analysis of consumption expenditure in several large-scale representative surveys similar to those described in Section 2 of this report. Drought tolerance was estimated to increase productivity by 25% in beans. This is an important result because beans are sometimes perceived to be a non-dryland grain legume (ISPC 2016).

The results for *Phaseolus* in the consumption expenditure surveys represent a sharp departure from those presented earlier for sorghum and millet. In Uganda in rural areas, the highest expenditure quintile spends 3x as much on common bean as the lowest expenditure quintile. In urban areas, expenditure on beans peaks and plateaus in the second quintile onwards. This urban plateau is at a level below bean expenditure for the same higher income quintiles in the rural areas. In general, the descriptive analysis of per capita consumption expenditure in Uganda and in other countries points to high expenditure elasticities in demand for beans especially in rural areas.

2. Heat-tolerant chickpea, common bean, faba bean, and lentil. As befits a product line that is relatively new, heat tolerance has a relatively modest target of reaching 10% varietal adoption in heat-prone areas in ten years: modest by the expectations set for the rest of the CRP, but ambitious nonetheless. A low score on impact was the main reason why this product line was placed in the bottom half of the ranking by the review panel that noted that it was too early to gauge impact.

This product line features genomic laboratory and conventional field research (Maalouf 2016). Simulation modeling also plays a prominent role in the development of heat-tolerant varietal options. As such, ex-ante technology assessments of the value of heat tolerance using crop-based process models should be one of the by-products of this research in Phase II. Presumably, those assessments could be updated as the models incorporate new findings on the physiological parameters.

A few heat-tolerant materials are already making their way into farmers' fields. Heat-tolerant chickpea cultivar ICCV 92944 has been released in India, Bangladesh, and Myanmar. Early acceptance is promising. In Phase II, the performance of this variety needs to be tracked over time to determine if heat tolerance per se is important in leveraging adoption outcomes. A rapid rural appraisal of the role of heat tolerance in the widespread diffusion of pearl millet hybrids in Rajasthan would complement the intensive monitoring of the fate and perceived determinants of early adoption of the first batch of heat-tolerant pulse cultivars available to farmers.

Anecdotal evidence suggests that heat tolerance is very important in increasing faba bean production in the north of The Sudan in irrigated growing conditions. (That experience should also be documented). Heat tolerance would seem to be at a premium in the production of irrigated summer millet in Gujarat. In principle, irrigated summer millet could also be a promising cropping system for the Sahel (T. Hash, personal communication, 2014). Irrigation in summer conditions would appear to establish the upper bounds of the expected value of heat tolerance for dryland cropping in the rainy season.

3. Short-duration, drought-tolerant and aflatoxin-free groundnut. Unlike the other seven crops in the Grain Legume CRP, groundnut has a stand-alone product line. Developing and deploying short-duration, drought-tolerant, nutrient-dense, and aflatoxin-resistant cultivars to catalyze production and competitiveness of groundnut value chains is its overriding goal (Janila 2016). Research in Phase I was supposed to focus on Niger, Tanzania, Uganda, India, Mali, Malawi, Senegal, and Vietnam. The bulk of the research that was reported was carried out in East Africa and in India. Transgenic options potentially contribute to solutions to drought stress and aflatoxin contamination.

Low grades that were less than half of the maximum on perceived outputs and impact resulted in a low score for this product line by the review team. However, the team did highlight several notable achievements that were not related to publication record.

Groundnut research in East Africa has been highly successful especially in Malawi in terms of varietal development and release, adoption, and innovative seed production. That 30-year experience is well documented in the recent ex-post impact assessment by Tsusaka et al. (2016). Investing in groundnut research in East Africa essentially needs to stay the course in Phase II.

In contrast, groundnut research in West Africa was not that visible in Phase I. The recent review of Phases I and II of TL II shows that about 13,000 tonnes of seed of improved varieties were made available to groundnut-producing households in West Africa (Monyo and Varshney 2016). But varietal release did not meet expectations. Other grain legumes, such as cowpea, seemed to make more progress in varietal outputs and strategic research outcomes than groundnut. IITA cowpea researchers and their partners somehow found a way to perform well in spite of low NARS research intensities characteristic of West African R&D.

Outsourcing field testing of on-farm groundnut varietal trials to NGOs that do not have a comparative advantage in research in Africa RISING was indicative of a lack of critical mass to get the job done. Mali was the only country and ICRISAT the only institute that relied heavily on NGOs for adaptive research. Not surprisingly, such outsourcing was underscored by the Africa RISING review panel as showing a lack of commitment to this large USAID-funded project.

Groundnut R&D in West Africa needs to be strengthened so that it can participate more actively in Phase II. Without a more active response from West Africa, this product line will continue to be running like a tricycle with one flat tire.

Some observers view groundnut has an uncompetitive oilseed with limited prospects for varietal change given the apparent permanence of so-called ruling varieties in farmers' fields (Pachico 2014). Of course, groundnut should be well-represented in Phase II. Groundnut has the highest value of production of the 12 Phase I crops (Table 1). The estimates in Table 1 also testify to its wide adaptability. It is produced in an appreciable area in 10 of the 15 target countries.

Moreover, recently, the crop has been characterized by unusual dynamism especially in international trade. Globally, a tipping point has now been reached when more kernels are eaten than crushed for oil. Demand for groundnut is very strong in China, the world's largest producer, so much so that within ten years it is likely that China will be converted from a net exporter to a net importer of the crop.

In comparison to the early 2000s, India has increased its groundnut exports, mainly in kernels, by fivefold. Indonesia is the largest importer. Ironically, India has found a way to compete internationally with Southeast Asia in palm oil: export groundnut in edible form to the countries it imports oil from. From January 2014 to November 2016, groundnut-related exports from India totaled US$1.7 Billion USD. Indian exports are primarily destined to Southeast and East Asia: (1) Indonesia, (2) Vietnam, (3) Malaysia, (4) Philippines, (5) Thailand, and (6) China. These six countries account for about 83% of the value of India's exports.

The title of this product line also seems to sow the seeds for faulty perceptions. "Aflatoxin-Free" sets the bar too high and equates to failure when strict standards denoting "Aflatoxin-Free", such as those of the EU, are not reached. Tying the success of the only product line for groundnut to aflatoxin outcomes is a risky strategy. Misperception is reflected in the review team's evaluation:

"Assessment of aflatoxin contamination of grain legumes showed that the major impact target of PL3 – to reduce aflatoxin contamination – is still far from being met. A contamination rate of 95% was reported (over 20 ppb) and although further mitigation efforts are planned there was no detail of these presented (University of Reading, p.125)".

Hence, the success story – 30 years in the making – of improved varietal change in East Africa is discounted and tainted by the fact that aflatoxin contamination is still a problem. Setting the bar high would make sense if the target is readily achievable. It isn't. Aflatoxin-mitigation practices are akin to bio-fortified varieties. Farmers, traders, and consumers do not realize that they have a problem; hence, demand for solutions is limited. Massive education campaigns are needed to enhance clients' willingness to pay for solutions. During the review of the aforementioned Africa RISING project in Tanzania, farmers did not seem that interested in testing biocontrol components in their fields nor could they articulate well why they were doing what they were doing. Other farmers did seem to be genuinely interested in deploying harvest and post-harvest management practices to reduce the odds of aflatoxin contamination once production became a reality.

Conceptually, it may be productive to transfer all the aflaxtoxin- and biofortified-related R&D to A4N in Phase II. Aflatoxin reduction and biofortification are two quite separable, challenging research areas that share the same demand constraint. To say they are challenging is an understatement. They require deep-pocketed, long-term donors who can tolerate lack of progress in short and even medium term.

A4N may also be a better locus for marshalling critical mass in mounting larger scale pilot programs that test well-known maize and groundnut aflatoxin-reduction practices in environments where lowered aflatoxin incidence is likely to lead to increased demand derived from higher economic returns. For groundnut, the Peanut Basin Senegal would be an interesting choice for such an R&D venture. What is the real cost of a program that meets EU standards and sampling requirements? How sizable are the benefits? Could an ambitious pilot aflatoxin reduction program lead to less groundnut crushed and exported as oil and more output exported in the higher priced confectionary market?

The finding that drought tolerance and the level of aflatoxin contamination are independent reinforces the argument for research separability. Therefore, drought tolerance and aflatoxin-free is not as natural a fit as is heat tolerance and drought tolerance or phosphorous adaptation and drought tolerance in other product lines.

Given past success, the absence of a product line in the Phase I GL CRP on disease resistance, especially foliar disease resistance, was a surprising omission. Presumably, there are potential complementarities in using the same phenotyping and genotyping facilities to identify and evaluate sources of resistance to the major fungal and bacterial diseases across several of the grain legumes. Such work would seem to warrant a higher profile than it received in Phase I.

Lastly, a transgenic option as an Aflatoxin-Free cultivar seems like a poor fit for the EU where the odds are heavily stacked against the acceptance of GMOs. There may be some lessons emerging from India's recent export experience that can also be transferred to SSA. How was India able to expand exports while satisfying requirements on aflatoxin contamination in Southeast Asia?

4. High nitrogen-fixing chickpea, common bean, faba bean, and soybean. This product line centers on R&D on biological nitrogen fixation. Phase I target countries that are still relevant in Phase II are numerous and include Ethiopia, India, Kenya, Malawi, Morocco, Mozambique, Nigeria, Tanzania, Uganda, and Zambia. The goal is to identify both germplasm and rhizobia with high SNF under stress conditions, demonstrate it on-farm, and make it available to the stakeholders (Chaturvedi 2016). Positive interactions between Rhizobia and P are emphasized.

This product line received substantially lower scores than any other. It scored poorly on output, impact, and coordination.

Inferior perceived performance of this product line by the review team cannot be attributed to budgetary constraints vis-à-vis other product lines. It ranked second in W1/W2 monies, bilateral support, and in total funding.

Lack of coordination, microbiologists, and integration with N2 Africa were cited as the main determinants of low output and impact. CIAT and IITA are very active in N2 Africa but ICRISAT and ICARDA were not cited in that program's Phase I final report. ICRISAT and ICARDA are still not mentioned on the N2 Africa website even though chickpea and groundnut figure prominently as priority Phase II crops along with beans, cowpea, and soybean. The dryland GL CRP is also conspicuous for its absence in N2 Africa-related literature.

The R&D emphases of N2 Africa are somewhat similar to the USAID-funded NifTAL project that started in 1979 and finished in the mid-1990s with a global mandate for improving BNF in developing countries. NifTAL's outstanding achievement was the training of many young scientists in quality inoculant production at the University of Hawaii.

I am not aware of many *ex-pos*t impact assessments of BNF-related success stories where investments in agricultural research were critical for their realization. It is a complex area where response is characterized by a high level of location specificity. Domestic production of quality rhizobia continues to be a very challenging proposition for most developing countries.

The *ex-post* impact assessment study cited for this product line at the October 2016 Final Results Workshop for Rwanda and Uganda really did not have that much to do with BNF per se. LaRochelle et al. (2015) is a high-quality, ex-post assessment but biological nitrogen fixation is not mentioned. Good potential for BNF likely contributed to the higher yield performance of several climbing and bush bean improved varieties that were adopted, but there were many other contributing factors.

In going forward, this product line needs to be substantially restructured or divested of. The additionality of this work over and above what N2 Africa is already doing seems small. In India, I assume that pretty much the same work on chickpea would be realized albeit at a lesser level of intensity if this work was discontinued.

Additionality implies a highly symbiotic relationship with N2 Africa. Presumably, germplasm identification for groundnut and chickpea for BNF potential would be complementary for N2 Africa's program which is the core bilateral project in going forward if this work were to receive priority as a product line. Alternatively, the Phase II CRP could focus on 2-3 'second' tier target countries of N2 Africa or on CRP Grain Legumes that are outside the ambit of N2 Africa. For example, improving rhizobial quality has loomed large as a priority in USAID's Mission assessment of the scope for increasing soybean production in Mozambique.

However, additional coverage would be a risky alternative assuming that N2 Africa's priorities respond well to demand. Additional coverage would also imply the need for strengthening microbiology, which did have a presence in terms of two IRS and several national Ph.D. scientists in ICRISAT from the mid-1970s well into the 1980s, but was not sustainable with tighter budgets in the 1990s and early 2000s. The focus of that earlier work was outlined as follows:

"Our emphasis will be on, biological nitrogen fixation by pulse and forage legumes, and by bacteria closely associated with the roots of the cereals, sorghum and millet. We will examine the numbers of rhizobia in the soils of Semi-arid tropics capable of nodulating the legumes in the ICRISAT crop improvement programme, namely pigeon pea, groundnut and chickpea, and will look at the effect of season and cropping sequence on these numbers" (Peter Dart 1976).

Other considerations also affect the priority that BNF should have in Phase II. Organizing the CRP around a cropping systems framework — a recommendation of both the DC and GL reviews — would increase the demand for BNF-related research. Excluding soybean would diminish demand. Nonetheless, going forward with BNF R&D really depends on N2 Africa. If N2 Africa believes that the benefits from cooperation and collaboration with the forthcoming CRP exceed the costs, then there is a firm foundation for the continuity of this product line. If they feel that the costs outweigh the benefits, then this product line should be divested of.

5. Insect-smart chickpea, cowpea, and pigeonpea production systems. The targets are the pod borers Helicoverpa and Maruca that annually inflict several billion USD loss on pigeonpea, chickpea, and cowpea. If Bt cotton in India is any indication, the economic value of full success in this product line would arguably be greater than equally positive outcomes in the other seven GL product lines combined. Factoring in negative externalities from pesticide application would add to this product line's overwhelming economic importance.

The target countries in Phase I are Benin, Burkina Faso, Ghana, India, Morocco, and Nigeria. 'Insect smartness' is characterized by many technological components including biopesticides, 'soft' insecticides, bio-control agents, and transgenic varietal options (Tamo 2016). These can be stereotyped into two complementary prospective technologies: IPM options and Bt varieties. The IPM options buy time while transgenic varieties are being developed.

Insect-smart production systems scored moderately well on all aspects rated by the review team. Coordination across Centers and crops was also singled out for praise.

Despite its potential to generate truly massive economic benefits, this product line ranks the lowest in Full-Time Equivalent Scientists raising the concern of sufficient critical mass to get the job done. Its cadre of 4.5 FTE scientists is significantly below the average of 10.7 per product line in the GL CRP in Phase I.

Of the IPM options, the bio-control agents for pod borer appear to be one of the most novel and potentially interesting. As the scientists in this research area point out, IPM is highly localized in its application. Historically, IPM has generated a positive but low rate of return on investment in the CGIAR because of its limited widespread adaptability. The salient exception is biocontrol of cassava mealy bug in SSA.

Development of Bt pigeonpea, cowpea, and chickpea are the big-ticket items in this product line. If successful, it will be the major contribution of the envisioned Dryland Cereal & Grain Legume CRP in Phases II or III. Insect-smart transgenic technologies require more emphasis and a more aggressive approach than they received in Phase I. The conclusion of the review panel resonates:

"On-farm dissemination of non-chemical approaches to pest management is exemplary, but efforts to introduce novel genes and traits into grain legume species for host plant resistances are weak, and unless the focus of research is changed significantly will not deliver the projected goals in reduction of synthetic pesticides through the development and characterization of chickpea, cowpea, and pigeonpea transgenic events with high levels of resistance to pod borers" (University of Reading, p. 138).

The value of reducing pesticide use pales in comparison to the economic importance of potential productivity gains generated by the application of transgenic insect smart varieties, a prospective technology that warrants greater priority in future phases of the CRP.

6. Extra-early chickpea and lentil varieties. This is a well-defined product line that responds mainly to the opportunity for growing a short-duration legume crop on residual moisture following rice in areas too hot for wheat or where irrigation is deficient to raise a well-watered medium-duration, post-rainy season crop. The goal is to bring at least 500,000 ha of rice fallows into double cropping with chickpea and lentil (Agarwal 2016).

The geographic research domain addresses the last frontier for crop cultivation in land-scarce South Asia and is estimated at 15 million hectares for rice fallows. The South Indian States of Karnataka and Andhra Pradesh are the target areas for chickpea; eastern India, Nepal and Bangladesh represent the geographic domains of interest for lentil.

Like all the other product lines, there are some additional researchable areas included in this one, but extra-early chickpea and lentil has greater specificity than most of the others. It is also characterized by a lower budget that is about 50% of the mean across the eight product lines. Counterintuitively, the three product lines ranked lowest in budget were assessed in the top half of performance based on the review team's scores. Hence, the review team's assessment suggests some gains to be had in reallocating research resources in Phase II.

Producing a viable second crop on receding moisture after rice is a taxing proposition. The widespread adoption of JG 11 in Andhra Pradesh provides grounds for optimism. This is the product line in which it seems to make sense to take one of the review team's recommendations to heart: invest in agronomy. More than 15 million hectares in a well-specified cropping system should be a large and sufficiently homogenous area to generate international public goods. Focused land and water management could also make a productive contribution. Of the 15 Dryland Cereals and Grain Legume product lines in Phase II, extra-early chickpea and lentil is the one where the need for timely applied research in agronomy and in land and water management is transparent.

Crop management research figures prominently in lentil investigations in Bangladesh and Nepal. Comprehensive mapping of rice fallows in an assessment of potential for double cropping rice followed by lentil should provide a firm foundation for targeting both varietal development and the generation of key management practices. Mapping is the easy part. Selecting a few areas of high production potential for multiple cropping and actually increasing cropping intensity in those areas is considerably more difficult. Multiple varietal releases of early lentil in Bangladesh, Nepal, and India and of early chickpea in India and Myanmar enhance the odds that this product line will meet its 10-year target.

Scientists in this product line should liaise with those in the CSISA project housed in the Maize CRP. As mentioned earlier, success in the rice-wheat consortium in Punjab, Haryana, and western Uttar Pradesh and later in the CSISA project in Bihar and eastern Uttar Pradesh was predicated on being able to advance the planting date of wheat by about one month. Minimum tillage and earlier rice varieties facilitated that change. In rice-pulse systems, the potential for advancing the planting date of the second crop may be negligible, but its potential should be one of the researchable issues to be addressed. Scientists in this product line recognize that collaboration with rice researchers is needed to maximize system productivity.

CSISA Project scientists would benefit substantially from interacting with their counterparts in the extra-early chickpea and lentil product line. Adaptive research by CIMMYT agronomists on increasing cropping intensity in current rice-fallow systems in Odisha and Nepal has not been that successful in generating outputs that could translate into practical impact. It appears that more strategic thinking and research, such as evidenced here, is needed.

The uptake and consequences of improved lentil varieties in Bangladesh and chickpea cultivars in Myanmar are prime candidates for impact assessment in Phase II.

7. Herbicide-tolerant, machine-harvestable chickpea, faba bean and lentil varieties. This is the most novel product line in Phase I of the Dryland Cereals and Grain Legumes CRPs. It focuses on weeds and machines, almost entirely from the perspective of varietal development. This product line is comprised of three prospective technologies: (1) Improved faba bean varieties resistant to the parasitic weed *Orobanche*, (2) Tall, erect chickpea, lentil, and faba bean varieties amenable for machine harvesting, and (3) Improved cultivars tolerant to post-emergent herbicides (Gaur 2016). Transgenics and mutation breeding will be used to develop herbicide resistance.

The 10-year targets are twofold: (1) improved cultivars with herbicide tolerance developed and evaluated and (2) at least 10% of crop area in target regions brought under the improved varieties amenable to mechanical harvesting. India in chickpea and Morocco for faba bean are two of the important country by crop combinations. One prototype tall chickpea variety has recently been released in India.

Of the three prospective technologies listed above, the development of elite machine-harvestable material is the most advanced with 21 chickpea, lentil, and faba bean varieties released mainly in the Middle East and Central Asia. In Phase I, about 5,500 tonnes of seed of these varieties were made available to farmers. Herbicide tolerance is still in its formative stages. In Phase I, only two publications are listed for this product line in the Open Access Repository of ICRISAT's library (Chaturvedi et al. 2014 and Sajja et al. 2015).

The product line has the highest proportion of W1/W2 funding, and its publications submitted to the Review Team reflect a high intensity of basic genomic research that would appear to be a necessary precursor to the development of tolerance to post-emergent herbicides. In spite of a high overall rating, the review team's evaluation is peppered with questions about the conceptualization and quality of the research. Identifying and developing natural sources of resistance to a parasitic weed in faba bean improvement is business-as-usual for the CGIAR, but developing transgenic herbicide resistance is not.

Generating machine harvestable varieties is not as novel, but it also has a potential for negative unintended consequences if mechanization is subsidized with cheap credit as it usually is. Any negative impacts can be minimized somewhat if machine harvestable varieties do not yield as well or fetch the same prices as their spreading counterparts. In this case, there would be incentives for larger farmers to plant and machine reap erect types and smaller farm households to stay with and harvest their higher yielding spreading types if labor costs were really that binding.

I agree with the Review Team's recommendation that this project line could benefit substantially from input from social science, particularly economics. Specific issues are the following:

- Transgenic herbicide tolerance is unlikely to benefit individual private-sector seed companies because plant varietal protection is not effective in India, but it could preferentially benefit herbicide suppliers as demand for specific products would increase if transgenic tolerance worked. In this case, transgenic herbicide tolerance becomes an international private good unless it has the potential to apply to all chemicals equally well. International public-goods research should stop at proof of concept; however, proof of concept may not translate into benefits in farmers' fields. If it hasn't already, this aspect of the product line should be vetted by a legal presence, well-versed in patent law and plant breeders' rights.
- The net benefits per hectare (in this case equivalent to cost savings) of successful research in herbicide tolerance and machine harvestable varieties appear to be an order of magnitude less than the size of per unit benefits in other product lines. Piece rates for harvesting are most likely secularly rising over time, but equivalent wages are unlikely to be as seasonally high as other times of the year. Incurring labor costs of 32% of production costs, as reported in the results workshop for Karnataka, does not seem to be sufficient to trigger a demand for machine harvesting. Finding sizable economic losses from manual weed control practices needs to be documented by both agronomists and economists.
- The use of pre-emergent herbicide and the additionality (in terms of productivity gain) for post-emergent herbicide needs to be quantified for chickpea and lentil in India. Seemingly, it would be difficult to justify using post-emergents if pre-emergents are not yet in use.
- Field size in chickpea and lentil is unlikely to be sufficiently large to support large migratory combine harvesting. Smaller combines with more localized operators are needed to make mechanical reaping worthwhile. Those combines may have to be imported from other countries, in particular China, if the results of the CSISA Program in the rice-wheat belt are indicative. In that program, adaptive machinery research was carried out in many locations, and hundreds of localized owners of machines were individually trained by research technicians.

Two sources of information that are available to research management in the GL CRP should be mined to address issues related to the desirability of investing in transgenic herbicide resistance and machine harvestable varieties in chickpea and lentil. For starters, the VDSA should have an abundance of plot-specific data on the costs of production on chickpea particularly labor costs over time for specific operations of relevance to weeding and harvesting. Secondly, follow-up research is needed to track the fate of the seed of these machine-harvestable varieties developed by ICARDA and their partners. Case study research on those varieties and on how machine harvesting came about in selected locations together with its estimated impact would be extremely informative for this product line. Ways need to be found to cost effectively quantify the opportunity cost of women's time in harvesting and what more time but less income would mean to the nutrition of their children in the household.

This research addresses the increasing reality of selective herbicide use and selective mechanization in grain legume production in several of the target countries. The GL CRP has taken a bold step with this product line to adjust its research portfolio to these changing production circumstances. In Phase II, herbicide use and mechanization should not be ignored, but the rationale for this product line should be strengthened via punctual interdisciplinary research to enhance the odds of success and to minimize the chances for unintended consequences. In particular, the case for investing resources in tolerance to post-emergent herbicides in Phase II seems weak and highly speculative.

8. Pigeonpea hybrids and management practices in India. Pigeonpea crop improvement in East and Southern Africa is also covered in this product line which is one of the most cost-effective ones in the CRP. Here I only focus on pigeon hybrids in India. As discussed in the next section, pigeonpea crop improvement in East and Southern Africa should feature as a separate product line in Phase II. Of the dryland cereals and grain legumes, pigeonpea is the most rapidly expanding crop in SSA. Production conditions and responses also differ between SSA and India. Gains from heterosis have not been observed in Africa where pigeonpea is produced mainly in maize/pigeonpea intercropping systems. In peninsular India, medium-duration pigeonpea is intercropped but maize/pigeonpea is not common. Therefore, the recommendation domain for pigeonpea hybrids is India. Myanmar figures as a spillover country where gains from heterosis have been amply demonstrated and rigorously documented.

Achieving an adoption area of 500,000 hectares in hybrid pigeonpea by 2022 is the overarching goal (Sameer Kumar 2016). Arrival at this target is not guaranteed, but it seems eminently doable. Since outcrossing and the gains to heterosis were first described in the mid-1970s at ICRISAT, a small cadre of pigeonpea scientists have persevered towards its commercialization. Steady progress has been made over the past 30 years. Presently, pigeonpea hybrids are estimated to occupy about 150,000 hectares in India (Sawargaonkar et al. 2016). Four hybrids have been released. Results from hundreds of on-farm trials consistently show productivity gains that average 20-40% over farmers' check varieties in each of the 4-5 States where pigeonpea is commonly grown.

The ISPC commentary on the full proposal for CRP II of the DCL queried the need to raise yield potential when the yield gap was large between best and farmer's practice. Hybrid pigeonpea is the answer to that question. It raises yield potential and reduces the so-called yield gap without significant changes in other management practices although application of phosphorus application can be complementary in the varietal change to hybrids.

Because pigeonpea has a moderately high multiplication ratio and is characterized by a low seed rate of only 10-15 kgs per hectare, hybrids are a cost-effective intervention even if they only increase productivity by 15-20%. Pigeonpea yields have been flat in India for decades; hybrids are the most exciting prospect to break this constancy (Saxena 2016).

Pigeonpea hybrids are not the sole source of optimism for productivity enhancement. The super-early duration material could also contribute to increasing output. Based on recent findings, the review panel also expressed enthusiasm for managing pigeonpea like a horticultural crop.

I would share that optimism if Bt pigeonpea were to become a reality. In the late 1980s, extra early duration cultivars were a valid hope to signal a departure from stagnating productivity. These very short duration photoperiod-insensitive varieties required sole-cropping systems. Farmers could not manage severe pod borer infestation even with 4-5 insecticide applications. They lost interest in those new cropping systems which they viewed as uneconomical.

Likewise, growing pigeonpea like a horticultural crop will be accompanied by increased pest pressure and pesticide load. Controlling biotic and abiotic sources of risk in a horticultural setting may capture the imagination of agronomists, but it conjures up images of impracticality to economists because pigeonpea can be more extensively produced in the countryside and because it doesn't have the potential to generate over five tonnes of output per hectare characteristic of vegetable crops under intensive management.

Disease incidence also appears to be increasing somewhat. Late blight is cited as a new disease particularly in wetter locales or in wetter growing seasons. Excellent progress continues to be made on the control of sterility mosaic and fusarium wilt, the two most economically important diseases of the crop. Late blight is a cause for concern because it could wipe out fields and not just plants within fields. Preventative spraying of fungicide is probably not economic in medium-duration material that is mostly intercropped. Host plant resistance will be needed.

Overall, hybrid pigeonpea in India is one of the most dynamic product lines in the GL CRP. The hybrids could be on the threshold of making a very large commercial impact, and, hopefully, their presence will begin to be fully felt in Phase II. With hindsight, the Bill & Melinda Gates Foundation definitely should have kept pigeonpea in Tropical Legumes III. The opportunity cost of excluding pigeonpea could be very high, indeed.

New Opportunities and/or Consolidated Prospective Technologies for Phase II

The 15 product lines in Phase I represent a firm foundation for going forward into Phase II. As discussed above, some streamlining or tweaking could improve the research agenda. Adding one or more product lines and consolidating others could also enhance effectiveness. Below are two areas for consideration:

Improved Pulse Varieties for Export to India from East and Southern Africa

As grain legume scientists increasingly recognize, India's upward trend in pulse imports is one of the most dynamic forces in international agricultural trade that potentially could affect smallholders in developing countries very favorably. This potential product line is an increasingly ripe candidate for bilateral funding and for inclusion in Phase II. The main pulse is pigeonpea. Enhancing the production of mung bean with assistance from AVRDC and introduction of black gram into ESA could also be contemplated. Tanzania, Mozambique, Malawi, and Kenya are the target countries. *Dhal* is the main form of consumption.

Brightening the prospects that smallholder pulse growers participate in and benefit from India's burgeoning import demand for pulses is the main objective of this product line. International trade in pigeonpea from these four target countries to India during Phase I totaled about 1.0 US$ billion from 2012-2016. Pigeonpea's import value is orders of magnitude greater than international trade of any other grain legume or dryland cereal crop in the DC&GL research portfolio. The value of mung bean exports have also been increasing over time from this set of countries to India.

From 2014-16, the three most recent calendar years, the value of Indian pigeonpea imports has averaged about 400 US$ million annually. From June 2015 to August 2016, the average import value per tonne exceeded US$ 1,000. Myanmar with a 38% share of exports is the only large competitor to African countries which collectively account for the bulk of pigeonpea exports to India and which feature countercyclical production to both India and Myanmar.

For pigeonpea, there are few if any viable threats that India's trade deficit in pulses is ephmeral, that India's demand will be satisfied by the import of substitutes such as cheaper Canadian peas, that large farmers will capture most of the benefits, or that developed countries, such as Australia, Canada, or the United States, will become competitive (Walker et al., 2015). Although the price of yellow peas is only 40% of the import value of black gram and pigeonpea, the peak prices of 2015-2016 did not lead to readily visible substitution of cheaper peas for dearer black gram and pigeonpea. Calendar year 2017 should be the worst-case scenario for imports with a decrease in demand from demonetarization and an increase in supply from a bumper pigeonpea crop exerting downward pressure on import prices. The value of imports will fall, but their quantity should still be substantial.

Earlier medium-duration varieties and cost-effective seed schemes are the main prospective technologies that should be the center of attention in this product line. More intensive maize/pigeonpea intercropping practices would also be useful to slow the area expansion of the crop. Earlier medium-duration varieties are needed to extend cultivation to national sub-regions such as Central Malawi where pigeonpea is not planted extensively because of open access to fields after maize is harvested.

Pigeonpea is not in Tropical Legumes III which is a serious omission. Pigeonpea was not in Tropical Legumes II in Mozambique where response to this emerging opportunity was dampened by the absence of breeders' and foundation seed of the new ICRISAT-related varieties. Everyone was scouring the country for seed. Because of its outcrossing habit, seed production for pigeonpea requires more attention than for other pulses. Monitoring varietal change and undertaking adoption research are difficult undertakings.

Improving Soil Fertility in Dryland Agriculture.

Dryland agriculture in the target countries in Africa and in India is synonymous with low soil fertility. Indeed, poor soils are the most important constraint limiting intensification of agricultural productivity in Africa (Fisher, et al., 2014). In an article in *Nature* titled "No Silver Bullets for African Soil Problems," Ken Giller (2012) summed up the current state of soil fertility in Africa:

"*In relation to inherent productivity, native soil fertility is less than half that found in Europe, as the vast majority of soils are relicts of 2-billion year old granites, and have few nutrients left. Where younger, volcanic soils occur these are inherently richer in nutrients, but have their own soil fertility problems as they generally fix phosphorus strongly. Soil fertility is also extremely heterogeneous at more local scales." (p.41).*

There are no magic solutions to soil nutrient deficiencies or toxicities; to maintain productivity mineral fertilizers are necessary (Smithson and Giller 2012). They should be used in judicious amounts and coupled with improved organic matter management.

In Phase I, soil fertility management was not neglected in the three dryland CRPs, but it did not receive the attention that it deserved. At best, the investment in soil science in terms of senior scientific staffing was maintained as little if any critical mass appears to have been added in this important area. Supportive social science research, particulary in economics, was negligible.

Yet, largely because of the high productivity of K.L. Sahrawat, S.P. Wani and their colleagues at ICRISAT Center and A. Bationo at IFDC, the cupboard is well stocked in terms of prospective technologies that score well on international public goods characteristics in this research area that is often characterized by a high level of location specificity.

Prospective technologies for improved soil fertility management need to be chosen carefully. Some are impractical and/or entail high opportunity costs. For instance, green manuring is impractical in African dryland conditions because the rainy season is too short for the early incorporation of green manures followed by the cultivation of a food crop in the same season. Conservation agriculture is constrained in many locales because of a high opportunity cost in the use of crop residues or in the demand for seasonal family labor.

This product line applies to all crops in Phase II. The following prospective technologies are candidates for greater emphasis in Phase II and are ranked roughly in the order of past investment in them:

Microdosing N and/or P. Nitrogen and phosphorus are the macro-nutrients most lacking in dryland soils in Africa and India. Nitrogen needs to be supplied continuously. Sources include fertilization, green manuring, legume rotations, or leguminous tree-shrub fallows. Phosphorus can be managed as a stock, but to achieve this, external inputs of inorganic phosphorus are essential (Smithson and Giller 2002). Use of phosphorus-efficient varieties and crops is only a temporary and second best solution. Sooner or later, the soil stock of phosphorus has to be replenished.

Some R&D was carried out on microdosing N and/or P in West Africa, but, in general, its visibility declined in Phase I. Microdosing is still a relatively young technology that has been scaled up to about 160,000 farmers in Zimbabwe where it was initially developed with an interesting marriage of simulation modeling and extensive on-farm verification in the early 2000s (Twomlow et al. 2009). By 2009, about 25,000 farmers in Mali, Niger, and Burkina Faso had used microdosing to improve their cereal productivity. Value:cost ratios in cereals typically ranged between 2-4 with microdosing technology compared to the control of no fertilizer (Tabo et al. 2007). Microdosing gave roughly equal or superior productivity outcomes to higher recommended doses of N and P. Widespread technology testing financed by FAO featured project investments in agro-input shops, an inventory credit system, and intensive farmer training using demonstration plots.

As an emerging technique, the potential for spillovers with microdosing is sizable. It is being tried on multiple dryland crops in several countries and regions such as western Sudan where fertilizer application is rare (Osman et al. 2012). Early findings from research station and farmer trials in Sudan indicate that microdosing is a low risk, affordable technology that can generate significant productivity gains in cereals and to a lesser extent in grain legumes.

In Phase I, microdosing figured prominently in three of the Dryland Cereals product lines. It has also been tested extensively in grain legumes with a focus on P.

As in Zimbabwe, it is also a technology that can be used to generate positive outcomes in drought relief. Back-of-the-envelope calculations suggest that a US$ 20 million investment in microdosing in 2004 could have largely averted the need for emergency relief in Niger during the drought of 2005 (Bationo 2012). Donor relief efforts totalled US$ 80 million, and more local food production in 2004 would also have incurred savings for consumers from price rises in 2005.

Although yield gains are more assured when farmer use better agronomy, such as a clean second weeding, the positive productivity consequences to microdosing appear to be robust. The generalized strategy of adaptation to a regional or even sub-regional context also seems to work quite well with the judicious use of on-farm trials and yield-response simulation modeling. Nonetheless, the recommendation domain for microdosing needs to be rigorously evaluated as it is likely to be quite time- and space-specific. Microdosing is not the optimal way to maximize the return to the farmer's labor when the scope for area expansion exists; it is potentially a very cost effective means begin the early stages of intensification. Subsidizing fertilizer, such as the recent policy pursued in Mali, decreases the demand for microdosing which also is made obsolete when fertilizer availability becomes widespread.

Aside from defining a realistic recommendation domain, selective applied and adaptive research should be carried out in Phase II to transform microdosing's promise and potential into reality. Reducing the labor intensity of microdosing is the main challenge facing researchers. The private sector can play a role in contributing to solutions to the problem of heightened seasonal labor intensity of the technology. Pelleting the correct dose per plant as a tablet and coating seed with fertilizer are some of the options (ICRISAT 2009).

Microdosing also works fairly well when application is delayed after sowing which often corresponds to a peak in demand for seasonal labor (Hayashi et al. 2008). Higher preseason rainfall in May and June in the Sahel is positively associated with a higher response to P. Applying organic amendments, such as manure, with mineral fertilizer in microdosing most likely amplifies the size of a seasonal labor constraint.

Many of the testing/extension programs have involved explicit or implicit subsidies. Economic results show that microdosing is attractive without subsidies, but farmers need to be weaned from subsidies to make microdosing sustainable and demand effective. Follow-up adoption studies in the spirit of Pender et al. (2008) are required to assess the acceptance of the technology following the termination of donor and government subsidies. In these assessments, farmers need to be able to access the specifications of the microdosing technology from agro-dealers at cost. The degree to which microdosing introduces or reintroduces farmers to fertilizer in general is an important aspect of the technology, but more telling is the potential for adoption of microdosing itself, which is a risk-reducing technology compared to acceptance of recommended doses that are 3 to 5 times as costly. Ideally, monitoring of adoption needs to be conducted 5-10 years after the testing programs have ended to determine the sustainability of microdosing and the degree to which it has led to increasing fertilizer-use intensity.

At the end of Phase II, the Dryland CRP should be in a position to either graduate out of microdosing as a prospective technology because its early acceptance is perceived to be sustainable or to divest of microdosing because its recommendation domain in terms of space and time is too small to warrant more investment in research. To arrive this decision point with full information after two decades of R&D, microdosing warrants research resources in Phase II, primarily in soil science and secondarily in economics.

The finding that microdosing may negatively affect nutrient balances thereby making the technology unsustainable also warrants longer term experimentation to arrive at well-defined recommendation domains (Ibrahim et al. 2016). In principle, nutrient mining is fine as long as nutrient stocks are ample (Vanlauwe and Giller 2006). Phase II should provide the means to and the venue for longer-term experimentation particularly with regard to the effect of microdosing on the stock of P.

Increasing the dosage of DAP in microdosing could be warranted because applied P during the cropping season has a residual effect on productivity in subsequent cropping seasons. For example, the severe drought in West Africa in 1984 led to widespread crop failure at the ISC and in the four ICRISAT-study villages in Niger. However, a dose of 24 kgs/ha of P applied in on-farm tests in those villages in 1984 was still profitable because of its positive effects on production in 1985 (ICRISAT 1986).

In general, a commitment to long-term experiments was not that visible in Phase I in research on soil fertility and crop management. Several of the recent publications in the ICRISAT Library are based on experiments that were conducted in the 1980s, 1990s, and early 2000s (Yamoah et al. 2011). Long term on-station experiments are difficult in cropping systems that feature extensive fallowing. Continuous cultivation on sandy soils results in low yields for the farmers' control treatment and nutrient depletion of organic matter irrespective of most agronomic practices. Fallowing treatments need to be factored into those experiments that have a decided international public goods character. Modeling is not a perfect substitute for but rather a complement to long-term experimentation which should receive more emphasis in Phase II than it did in Phase I.

Increasing the Use of Fertilizers that Supply Boron, Zinc, and Sulphur. Based on intensive trialling from 2002-2006 and subsequent widespread testing, dryland soils in peninsular India are deficient not only in N and P but also in boron, sulphur, and zinc (Sahrawat et al. 2007). Balanced doses of these five multi-nutrients resulted in not only a substantial response in yield but also an appreciable increase in nutrient density in N, S, and Zn for in both grain and straw (Sahrawat et al. 2008). These findings can result in practical impact along several outcome pathways: (1) changes in fertilizer recommendations by State Departments of Agriculture, (2) the incorporation of adequate levels of boron, zinc, and sulphur in blends by fertilizer suppliers, and (3) the uptake of more balanced fertilization by farmers. This research has potential to also have a pronounced impact in SSA. For example, scientists in the USAID-funded Africa RISING Program in Ethiopia have added included boron, zinc, and sulphur as treatments in their extensive testing program of yield response in farmers' fields. Positive results have stimulated interest in incorporating the two micro-nutrients boron and zinc and the secondary nutrient sulphur in commonly used blends. Balanced fertilization with these five multi-nutrients should be assigned priority as a promising technology for R&D in Phase II.

Increasing the Availability of Soil Phosphorus and Partially Acidulated Rock Phosphate

Soil available phosphorus is a theme that woven its way through both the DC and GL CRPs in Phase I. Adaptation to low stocks of phosphorus is a priority for three of cereal product lines in Africa. That available phosphorus interacts positively with BNF and negatively with drought stress was well-recognized and one of the relationships that defined research in the GL CRP.

About 80% of African soils are deficient in phosphorus. Ironically, about 80% of the global reserves of phosphate rock are also found in Africa (Bationo et al. 2012). In general, rock phosphate cannot be applied directly; it requires processing to be reactive and soluble.

P has been the subject of considerable research in West Africa especially at the ISC in Niger (Fussell et al. 1987). Numerous on-station and on-farm trials have shown that partially acidulated rock phosphate does not generate the yield response of triple superphosphate or single superphosphate; however, the productivity response of 50% acidulated rock phosphate can approach that of TSP and SSP. For example, analysis of a 10-year on-station and 15 farmer-fields trial shows that phosphate rock applied every three years resulted in yields that were 75% of equivalent doses of P from TSP and SSP (Yamoah et al. 2011). The most profitable and risk-efficient treatment was 50% acidulated rock phosphate in these extensive millet-growing regions where the soils are 95% sand with very low levels of organic matter and soil phosphorus.

Phosphate rock is beginning to be commercialized in SSA. In Tanzania, Africa RISING has supported the work of a fertilizer blending company. The recommended blend is called *Minjingu mazao* granular; this complex fertilizer is penetrating into farmer fields in benchmark villages. Blends with boron, sulfur and zinc are also becoming available. This initial commercialization has yet to translate into changes in the extension program's recommendations that still are cast in terms of TSP, SSP, and DAP. Monitoring and diagnosing the fate of these early efforts at commercialization is one aspect of research on available soil phosphous that warrants priority in Phase II.

To this observer, fears that increasing utilization of rock phosphate from a negligible base could stoke geo-political tensions over a scarce resource whose demand will peak in 2030 or imperatives that policies be put in place " that will enhance P recovery from human excreta from cities and return it to farming systems as an approach toward closing the human P cycle (Gemenet et al. 2016, p.6)" are misplaced bordering on risible in an otherwise comprehensive review of low P adaptation in sorghum and millet in West Africa. L.D. Swindale's suggestion is eminently more practical: Load up bags of acidulated rock phosphate in planes and apply them aerially over sorghum and millet fields.

Site-Specific Nutrient Management. Here, the term site-specific nutrient management is used loosely to include multi-year plus and minus on-farm trials of macro- and micro-nutrients to validate and update a regional or national government's fertilizer recommendations. In Ethiopia, intensive trials over time in the benchmark communities show that response to fertilizer is dryland wheat is conditioned by field position in the toposequence (Amede 2016). This research by an ICRISAT scientist was among the most interesting, relevant, and important that a review team of Africa RISING encountered in SSA. Response dependent on location on the toposequence was surprising to soil scientists and could change both fertilizer recommendations and blend composition in Ethiopia. The USAID Mission in Ethiopia is aware of its potential importance and has tried to foster its use in a recent project on the design of fertilizer recommendations.

The trials in Ethiopia not only focus on nitrogen, phosphorus and potassium but also on response to the micro-nutrients of boron, sulfur and zinc. They were patterned after the earlier discussed research in peninsular India. The response research in Ethiopia has the same potential to change the thinking about how soil scientists in the Ethiopian Institute of Agricultural Research analyze the results of comprehensive fertilizer trials in 64 *woredas*. Economists have been slow to recognize that changing recommendations in the public sector is an important policy impact of agricutural research. Indeed, it is easier to establish influence in decision making on recommendations than in almost any other type of policy that affects agricultural, economic, and social development.

Comments on other opportunities

These two additional product lines and their embodied prospective technologies do not exhaust the potential opportunities for Phase II. For example, farmer-managed natural regeneration could be incorporated into the 'pearl millet in Africa' product line with an emphasis on leguminous tree species such as *Acacia Albida*. The earlier described ACN ridge tillage technology could be another promising candidate to continue in Phase II from the Humid Tropics CRP. Some of these prospective technologies may be more thoroughly covered in other CRPs such as CCAFS or FTA in Phase II.

If funding is tighter in Phase II than in Phase I, the DCL will have to guard against being spread too thin in trying to cover the technology waterfront. Postharvest research is one area where the linkage with genetic improvement could be strengthened. Historically, postharvest research has not generated an attractive rate of return in the CGIAR. There may not be sufficient investment in human capital in this area or perhaps collaboration with the private sector is insufficient. ICRISAT has made punctual investments in this area, such as postharvest facilities in Bamako with IER and in Bulawayo with SADC, but proportionally not as much as other CG Centers, and I am not sure that the Institute or the CRP should invest in the future unless other participating Centers have specialist scientists who can be deployed. Value chain studies have not been that informative in identifying 1-2 key areas where investing in post-harvest research or allied genetic improvement would have promise to ameliorate binding constraints. Value chain analyses almost always generate interesting information, but they do not seem to be any more useful than market structure, conduct, and performance studies were in the past.

As shown in Table 4, oilseeds are predominantly dryland crops. In particular, sesame and sunflower are gaining ground in dryland agriculture especially in ESA. They are not labor intensive, can be mechanized or grown in smallholder agriculture, and are sources of rural non-farm employment in processing. Most oilseeds can be hybridized with favorable incentives for private-sector development of improved cultivars. With medium-sized farms becoming more numerous, oilseeds appear to be a viable option for agricultural youth to stay in agriculture by diversifying away from cereal production.

India presently exports about US$ 1.0 billion in castor oil used almost solely for industrial purposes. Castor is a robust dryland crop that grows in the wild in ESA where it could easily be cultivated. The dryland CRP could carry out a small scoping study in Phase II to determine if it in particular and the CGIAR in general would have a comparative advantage in carrying out very selective research on oilseed R&D that would potentially benefit agricultural youth.

Agroecologies, Systems, Integration, and Prospective Technologies

In Phase I, research in the DCL and the GL CRPs was framed from the perspective of a conventional commodity approach to crop improvement. Commodity and multi-commodity product lines in the case of the GL CRP were the operational constructs for organizing research at the level below and across the 4-5 Flagships. Crop management, land and water management, and post-harvest activities were imbedded in these priority crop product lines that each consisted of one or more well-defined prospective technologies.

This way of organizing research is similar to the RTB CRP in Phases I and II. The Humid Tropics is the most important agroecology for the production and consumption of root, tubers, and banana, and the RTB CRP seems to have been able to absorb some of the relevant elements Humid Tropics CRP that was active in Phase I without having to modify significantly their commodity approach to their research agenda for Phase II.

As described earlier, research in Phase I of the Dryland Systems CRP was organized in five sub-continental regions from the perspective of three agroecological systems: (1) Rainfed systems in seven action research sites and/or transects, (2) Agropastoral systems in four sites, two of which also addressed rainfed systems, and (3) Irrigated systems in two systems.

In going forward with a merged Dryland Cereal Legume CRP for Phase II the external review of the Dryland Systems CRP was concerned that the focus would be too narrow and fragmented on commerical agriculture driven by market considerations. For the review team, success would be predicated on highly positive interactions between strong systems scientists and senior social and economic scientists with excellent gender credentials. Rangelands and, more generally, integration of livestock, crops, and trees in a holistic systems vision warranted more emphasis than what was given in the pre-proposal. The review team recommended that "a holistic integrated vision linking socio-economics and agro-ecologies should be the driving force of the DCLAS CRP (Merrey et al. p.73)."

In this section, I briefly discuss the opportunity cost of not having a more integrated systems approach in terms of prospective technologies that have international public goods characteristics and, if successful, these technologies could be institutionally attributed to the CG Centers and its partners. In other words, what is significantly missing, if anything, by not organizing research around a more integrated, systems-based approach grounded in priority agroecologies? Before moving to alternative agroecological frameworks, the issue of disciplinary research resource allocation is touched upon in the next section.

Social Science and Disciplinary Research Resource Allocation

The vision that socio-economics and agro-ecologies should be the driving force of the Phase II Dryland CRP calls for a greater investment of social scientists relative to biological scientists. Historically, a few CG Centers, IFPRI apart, have invested heavily in social scientists, but the results have not been good in the sense of making a difference in terms of research resource allocation to prospective technologies. Numerous social scientists at ILCA in the late 1970s and early 1980s conducted anthropological studies on pastoralist behavior and production systems in Sub-Saharan Africa. Such research was justified on the need to diagnose pastoralist problems and constraints, but it became an end in itself. Research findings did not appreciably affect animal scientists' priorities, and both ILCA and later ILRI have not been able to leverage positive production, economic, and social outcomes in pastoral systems that are seemingly resistant to technological change for now well-know reasons.

More recently, the CRP on Aquatic Agricultural Systems (AAS) featured Participatory Action Research in dispersed geographic hubs where much of its work in Phase I was carried out. Both the AAS approach and the Dryland's Systems orientation seemed to have a lot in common in Phase I.

Participatory action research was intensive in its use of social scientists and evaluation so much so that several adoption studies were conducted from the viewpoint of the theory of change in the evaluation literature. The review team pointed out that from a research perspective, the value of such a theory is doubtful. More generally, the AAS evaluation team concluded:

While the emphasis on PAR may potentially contribute to the relevance and effectiveness of the program, to date this contribution has not been realized or convincingly demonstrated. Nor has a strong link yet been demonstrated between the use of PAR and quality of science.

The evaluation team concludes that to date, AAS has been led and managed primarily from perspective of using AAS as a way to establish and legitimize new skills and competences.

Insufficient attention has been given to the historic competences of WorldFish and other CGIAR centers…It is, therefore, the primary recommendation of the evaluation team that the CGIAR should justify further investment in aquatic agricultural systems more on the grounds of comparative advantage (CGIAR-IEA(b) 2016, p.xv).

Comparative advantage for the review team meant that the AAS in Phase II should focus more on research on fish per se, specifically fish breeding (C. Crissman, personal communication, 2016).

Overinvesting in social science including economics and in adaptive research is a slippery slope in the CG Centers. That is not to say that missing gaps socioeconomics are unimportant to be filled in Phase II. For example, at ICRISAT, economics in West Africa appeared to be missing in action in Phase I. Replacing Cynthia Bantilan at ICRISAT Center and Jupiter Ndjeunga in the ISC is a very important priority for the conduct of informative supportive research that has the potential to influence decision making on research resource allocation.

Agroecologies

Agroecologies are not new as a conceptual framework for the CG Center participants in the anticipated Phase II of the DCL. ICARDA has an area focus on the Arid Tropics, ICRISAT on the Semi-Arid Tropics, IITA on the Humid Tropics, and CIAT on the Tropics in general. For drylands, the simple agroecological classification based on an

Aridity Index in Table 3 shows what an agroecological perspective could add to the DCL in Phase II. The Aridity Index is a proxy for length of the growing season; dryland agriculture is grouped into four agroclimatic zones: Arid, Dry Semi-Arid, Wet Semi-Arid, and Dry Sub-Humid (Walker 2016). With this classification, it is relatively easy to locate prospective technologies, based on investment cost, in each zone with an eye towards resiliency or with an aim towards intensification. Twenty prospective technologies, five in each zone, are listed in Walker (2016) for SSA.

While the simple AI classification may be a good organizing construct for a paper on prospects for dryland agriculture, it appears to be too aggregate to be useful in research organization in Phase II. The potential for intensification is not linearly related to length of the growing season. Productivity is lower in the Arid and Dry Semi-Arid Zones, but cereal yields are not significantly different between the Wet Semi-Arid and Dry Sub-Humid Zones. Altitude is not factored into this climatic classification, and altitude strongly conditions the potential for intensification in East and Southern Africa.

Groundnut is the most adaptable crop in the DCL CRP. Its cultivation spans the most arid and the most moist of the drylands. Yet, the uptake of improved cultivars in West Africa is sensitive to the length of the growing season only in the lowest rainfall isohyet of 500 mm where mean adoption was only about 5% of groundnut-growing area in northern Nigeria (Ndjeunga et al. 2013). For the seven isohyets between 600 and 1200 mm, adoption was almost constant at 25%. These data do not suggest the need for very disaggregate agroclimatic production zones for West Africa for groundnut improvement research. They reinforce the conventional thinking that Sahelian, Sudanian and Guinean classification may be sufficient for most purposes. This classification was implicit in the research carried out by the sorghum and pearl millet product lines in West Africa in the Dryland Cereals CRP.

FAO Agroecological Zones and SPAM. Global priority setting for groundnut and pigeonpea (Mausch et al. 2013), millet (Nedumaran et al. 2014), and sorghum (Kumara Charyulu et al. 2016) was carried out during Phase I. These comprehensive excercises combined the agroecological zonation of the FAO with the Spatial Production Allocation Model (SPAM) of HarvestChoice. Homogeneous research domains were identified for each crop. These varied from 7 for pigeonpea to 17 for millet. Estimation of the size of spillover effects was featured in these innovative priority setting excercises. Estimated spill-overs were large in sorghum, millet, and groundnut, but small in pigeonpea because of unbridgeable differences in production domains (Mausch et al 2013).

Six of these production domains are in the warm tropics drylands ranging from less than 60 days to more than 150 days for the growing season. The warm tropics sub-humid with a growing season longer than 150 days is also of potential importance.

For both millet and sorghum, the production domain with the largest total and direct benefits is the warm tropics from 120-149 days. Viewed from the perspective of varietal adoption from the DIIVA study, spill-over benefits appear to be overestimated with this methodology, but the relative rankings of the research domains should not be affected that much, and the implications of the analyses should still apply.

The sorghum exercise goes as far as designating priority countries based on the size of 'real' benefits and the gap between 'ideal' and 'real' benefits. Countries receiving three asterisks indicating the highest ranking include India, Sudan, Ethiopia, Nigeria, Burkina Faso, Niger, Chad, and Cameroon. Five of the seven are in the set of Phase II target countries; Chad and Cameroon just make the highest priority status and Mali falls slightly short.

The authors of the other crops may also want to publish their discussion papers as research bulletins as was done for sorghum. They make for an impressive set of updated priority-setting studies that were the first to be carried out since the Medium-Term Plan of the Mid-1990s. In Phase II, the connection with ACIAR should be maintained.

Although very useful for priority setting, I do not see how the production domain concept could be operationalized in Phase II, because several countries have geographic areas in multiple domains. From the viewpoint of sharing intercenter resources in the CRP, the multi-crop organization based on like constraints and opportunities in the Phase I GL CRP is more appealing.

The Dixon Typology of farming systems. Capitalizing on CIAT's expertise in GIS and database analysis is one of the successes of the GL CRP. Achievement in this area is partially encapsulated in the DCL online Atlas.

Priority regions for the DCL focus crops were also delineated globally by Hyman et al. (2016). The study is based on John Dixon's farming systems typology that described 72 global farming systems in six developing regions in 2001. Priority for DCL R&D is attached to 18 broadly defined farming systems (Hyman et al. 2016). Seven of these are in Sub-Saharan Africa and South Asia and are comprised mainly of the focus crops produced in the target countries. Ranked roughly in order of extent of area, they are: (1) Rainfed mixed in South Asia (23%), (2) Cereal-root crop mixed in SSA (21%), (3) Agropastoral millet/sorghum in SSA (18%), (4) Rice-wheat in South Asia (11%), (5) Pastoral in SSA (11%), (6) Dry rainfed in South Asia (8%), and (7) Maize mixed in SSA (8%). This is very much a regional classification. The estimates suggest that the soil-related constraints are quite specific to each of the broadly defined farming systems, but most of the other variables, such as poverty incidence, are similar across the elements in this classification.

In this age of GIS and big databases, it seems that a decentralized approach is more effective whereby researchers can slice and dice data according to their own specific requirements in lieu of forcing them into a classification that may obscure and ill suit their purposes. In other words, scientists in each product line should have the freedom to arrive at their own agroecological classification according to their needs with the assistance of GIS-related expertise.

Cropping Systems. Only two of the 15 product lines are explicitly cast in the framework of cropping systems: postrainy season sorghum in India and extra early chickpea and lentil in India. Both reviews of the DC and GL CRPS recommend that the consolidated CRP adopt a cropping systems focus in Phase II. There are multiple aspects to this recommendation, but two of the salient ones center on the scope for generating and delivering new cropping systems to farmers and on the additionality in defining new component or multi-component technologies from a cropping systems perspective over and above the options that were discussed in the previous section.

In the drylands, sequential cropping is constrained by growing season rainfall which points to intercropping options or sole-cropped rotations as relevant for research. Cereal-legume rotations are important in principle, but farmers cannot always apply them in practice. Diagnostic research on hundreds of plots in India's village-level studies suggested that planning crop rotations is an inexact science. Only 60% of farmers' expected cropping season rotations were carried out as planned. Deviations between planned and actual sowings were attributed to changes in revised rainfall expectations from early season rainfall events, market incentives, and unexpected seed availabilities.

Row intercropping is common, and is executed in well-defined arrangements. Salient examples include maize/ bush beans and maize/pigeonpea in East Africa, and pearl millet/cowpea and sorghum/cowpea in the southern Sahelian and Sudanian zones of West Africa. These cropping systems are well-suited to dryland agriculture in SSA because the intercrops can be 20-30% more productive than equivalent areas of sole crops. Temporal and spatial complementarities in the timing of resource use and in exploiting space confer advantages to different species grown in proximity compared to the sole crops of the same species in the dryland Semi-Arid Tropics (Willey et al. 1983).

There are not many examples of new row intercropping systems that have been designed and tested on station and that have subsequently spread to farmers. Maize/pearl millet in West Africa is one of these rare instances where adoption rapidly rose to about 25-50 thousand hectares for a new intercropping system assembled mainly by researchers (ICRISAT 1986). Pearl millet is the longer duration crop and is planted at the $2^{nd}/3^{rd}$ leaf stage in maize (Shetty et al. 1991). Maize/pearl millet is rotated with cotton in the south of Mali. In the 1980s in Mali, maize/pearl millet consistently gave superior returns of the five intercropping systems that were extensively tested. Determining the durability and extent of this cropping system 30 years after its introduction would be informative for deciding on the magnitude of investment in cropping systems research in Phase II.

Nowadays, S. Snapp's doubled-up legume combinations are among the most innovative cropping systems in dryland agriculture. Pigeonpea is sown with either groundnut or soybeans at higher densities than farmers' traditional practice. Pigeonpea/groundnut or pigeonpea/soybean are rotated with maize. In 2016, the government of Malawi officially endorsed the doubled-up legume system as a recommended practice. However, the government's policy of fertilizer subsidies discourages the adoption of pigeonpea/groundnut or pigeonpea/soybean. At a minimum, these systems warrant a watching brief on their early acceptance in Phase II. Strip cropping of cowpea with maize and soybean with maize was also new to farmers in northern Ghana in the USAID-funded Africa RISING Project.

Others would argue that a more effective way of doing business than investing in improved cropping systems research is to let farmers integrate new and improved seed into their own cropping systems. The role of researchers is to ensure that farmers have access to different varieties with different maturities and characteristics that fit into their cropping systems and somewhat location-specific circumstances. Strong demand by farmers for earlier-maturing cultivars in all crops may also erode the potential for temporal complementaries that condition the size of the advantage of intercropping vis-à-vis sole cropping. Climatic change is likely to further increase the demand for earliness.

The empirical evidence does not appear to support the contention that shifting the organization of the research portfolio from a product-line emphasis to a cropping-system format would be accompanied by gains in focus. A review of the evidence on the demand for characteristics did not show cropping-systems related traits ranked highly. In particular, farmers seldom mention that tested varieties were superior or inferior for intercropping or for sole-cropping systems compared to the varieties they were currently cultivating.

Turning to the additionality of cropping systems in uncovering heretofore latent technologies, we can examine past experience to see if a cropping systems perspective made a significant difference in research strategy. ICRISAT agronomists were the leaders and coordinators of a USAID-funded project in Mali that was active from 1979 to 1990 (Shetty et al. 1991). That project engaged in capacity building with IER and in sorghum and pearl millet crop improvement and cropping-systems research.

The breeding priorities identified at that time are very similar to those today. For example, in pearl millet improvement in the more arid North, breeders were advised to select for yield stability and resistance to downy mildew, insect pests, and drought after flowering. In the wetter South, intensification was the emphasis with materials that respond to inputs, downy mildew tolerance, and improved harvest index. Additionally, pearl millet breeders were counseled to work with food technologists to explore alternative uses for the crop as feed, forage, and food.

This project accomplished a lot, but the cropping systems orientation of the coordinators was not explicitly reflected in priorities for crop improvement. Again, I am not persuaded that shifting to a cropping systems focus is worth the candle. Most of the constraints and opportunities in the product lines have already been defined from a farming systems perspective.

Closing Comments

In coming to the end of this long, rambling report on priority setting, product lines, and prospective technologies, two additional comments are relevant. First, priority setting needs to be cast in the budgetary setting that the DCL CRP and the participating CG Centers find themselves in. Similar to a few CRPs but unlike most others, the DCL is anchored by large-scale, long-term projects and initiatives from donors. By the time Phase II ends in 2022, the BMGF will have funded research on dryland cereals and grain legumes for over 15 consecutive years. In the past, USAID and UNDP have also provided sustained funding on well-defined R&D for 12-15 years in projects that have exceeded US$5 million annually.

Project HOPE and Tropical Legumes are the source of real "core" support to the DCL. They are the closest things that we have to unrestricted core funds that accounted for the lion's share of the Centers R&D in the first 30 years of the CGIAR. W1/W2 funds are highly desirable, but they were too unstable in Phase I and are likely to fluctuate even more in Phase II to be considered in the same realm as erstwhile unrestricted, core funding.

With the notable exception of ACIAR, donors do not do a good job of priority setting. They rely on their gut. Their instincts can be very good, e.g. Rob Bertram at USAID. They can factor in many elements of constrained decision-making that are impossible to quantify. Their selection of target countries is well-thought out and usually makes good sense; however, the degree to which priority setting by the participating Centers have influenced their decision making in Phase I and the leverage results from comparable studies will have in Phase II with these key donors is unknown. Earlier in this report, the wisdom in not including pigeonpea in Tropical Legumes III or dropping Niger as a target country in Phase II of Project HOPE or continuing with sorghum in Tanzania in Phase II was questioned. The shift to Uttar Pradesh in chickpea in Tropical Legumes III also seems puzzling given the trend to greater production in central and southern India.

The above are the important decisions that are being made in regional and cropwise research resource allocation. Yet they appear to be mostly undocumented or poorly documented in terms of justification. In the current budgetary scenario, priority setting is diminished because the DCL CRP and the participating Centers only have some degree of influence on but do not have autonomy over research resource allocation. This appears to be a cost of doing business and seems like a small trade-off to make. Clearly, having bilateral support with a few very large key projects is preferable to not having such support in times of uncertainty.

Usually, the phases of these large projects are not synchronous with the phases of the CRP. Therefore, when the next Phase of the DCL begins, the priorities to a large extent are already given by the current Phase of Project Hope, Tropical Legumes, and any other large medium-term R&D Projects. This budgetary reality decreases the demand for priority setting. Why invest in supportive research on resource allocation that is unlikely to influence decision outcomes? Priority setting is still of potential importance, but it is not as great as if the DCL and participating Centers had access to ample, unrestricted core support or if, heaven forbid, they had to rely on a very large number of small and very small bilateral donor projects for support.

This is one of those rare reports where the author argues that the subject matter of interest is not that relevant. This perception is primarily driven by the view that generally the priorities in 15 DC & GL product lines were well-articulated and that they responded to real problems and opportunities from the perspective of generating international public goods in Phase I and, secondarily, by the budgetary context of the DCL CRP.

The second comment centers on the prospective technologies that will drive outputs, outcomes, and impacts in Phase II and beyond. Some options, like hybrid pigeonpea, have been a long time in coming. Others, like the balanced application of fertilizer featuring boron, sulphur, and zinc, are more recent. These prospects are the products of talented and dedicated scientists who worked in the best of times and in challenging times for over 25 years at the same CG Center. They include S. Beebe (at CIAT), the late K.L. Sahrawat, K.B. Saxena, S.P. Wani, P. Subrahmanyam, H.D. Upadhyaya, C.L.L. Gowda, S. Salim, F.R. Bidinger, E. Weltzien, T. Hash, F. Rattunde, B.V.S. Reddy, S.N. Nigam, M.C.S. Bantilan, F. Waliyar, H.C. Sharma, and R. Tabo.

These technologies and their supporting research have been vetted and reviewed numerous times in In-House Reviews, External Program Reviews, and, most recently, in the EEEC reviews held in 2015/16. Of these, the most rigorous were the annual In-House Reviews that were coordinated by Dr. J.S. Kanwar, ICRISAT's Director Research from the early 1970s to the early 1990s. When the scientist's presentation was not going well – as was often the case – beads of sweat would begin to accumulate on his or her brow in anticipation of JSK's dreaded question, "It seems to me that you have done enough in this area, why don't you move on to something else?" Fortunately, many of the above scientists stayed the course.

The Annual In-House Reviews provided an impartial venue where everyone could find out what everyone was doing and could evaluate progress made in the Institute's R&D as a whole. The brightness or (in a few cases) the bleakness of the prospects gradually became apparent.

Most of the prospective technologies described in this report predate livelihood perspectives, theories of change, or value chains. For many of us, the only thing that mattered was research with a farming-systems perspective. That was good enough.

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