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18 Varietal Generation and Output

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The substantive findings in Chapters 6–17 are synthesized and reviewed in this and the following chapter, which draw heavily on Walker *et al*., 2014. Findings are synthesized from two perspectives: a cross-sectional analysis across the 20 crops in 2009–2011 and a before-and-after comparison with the 1998 benchmark and the 2009–2011 data. Findings in this chapter are organized from the evaluation framework of inputs and outputs that was described in Chapter 3. Hypotheses from that chapter are revisited at the end of each thematic section. Where appropriate, results from South Asia reported in Chapters 13 and 14 are cited to provide a spatial benchmark for the outputs of data analysis in sub-Saharan Africa (SSA).

Varietal Generation: Full-Time Equivalent Scientists by Crop Improvement Programme

As discussed in Chapter 3, our emphasis on inputs in varietal generation focuses on full-time equivalent (FTE) scientists in crop improvement programmes in national agricultural research systems (NARS) broadly defined as public crop improvement programmes, universities and private-sector companies.[1]

Scientist numbers, research intensities, and congruence estimates

The total number of FTE scientists across the 151 national crop improvement programmes approaches 1300 (Table 18.1). The actual number engaged in crop improvement researcher is larger. For example, the 126 FTE scientists in rice refer to the time allocated by 289 researchers (Diagne *et al*., Chapter 10, this volume). Only about 25–30% of these scientists commit 75–100% of their time to rice research.

More scientific resources are allocated to maize than to any other crop in SSA (Table 18.1). Cassava is a distant second to the total for maize across its two major regions of production.

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Table 18.1. Full-time equivalent (FTE) scientists by crop improvement programme in SSA in 2010.

Crop	Countries	Total FTE scientists	Min.	Median	Max.
Maize (ESA)	9	243.2	12.0	17.0	62.0
Maize (WCA)	11	139.5	3.0	5.8	77.5
Cassava	17	138.8	1.0	7.2	22.5
Rice	14	125.0	0.9	8.3	15.3
Bean	10	86.5	2.6	5.9	21.4
Potato	5	57.3	3.0	4.6	30.0
Cowpea	18	76.5	0.4	2.9	16.0
Wheat	4	70.1	12.0	15.0	28.0
Soybean	14	52.2	0.8	2.4	14.6
Sweetpotato	5	32.7	2.0	4.0	15.9
Yam	8	49.5	3.0	4.6	12.1
Sorghum	7	42.3	2.4	3.0	18.2
Groundnut	10	23.9	1.15	2.1	5.0
Banana	1	40.0	40.0	40.0	40.0
Chickpea	2	27.0	8.4	13.5	18.6
Pigeonpea	3	6.9	3.9	1.2	5.0
Barley	2	22.1	1.0	11.1	21.1
Pearl millet	5	20.4	1.5	4.5	6.8
Faba bean	2	15.5	6.9	7.8	8.7
Lentil	3	11.0	2.0	3.7	5.3
Field pea	1	6.9	6.9	6.9	6.9
Total/mean	151	1,289	na	8.6	na

na, not applicable.

Maize in East and Southern Africa (ESA), with a longstanding tradition of national programmes promoting hybrids, has benefited from a sharp and sustained increase in private sector maize breeding, especially in Kenya, Malawi, Zambia and Zimbabwe (De Groote *et al*., Chapter 11, this volume). The private sector has yet to make its presence felt in maize production in much of West and Central Africa (WCA) where national programmes have emphasized Open Pollinated Varieties (Alene *et al*., Chapter 6, this volume). Nonetheless, relative to other crops, the public sector has allocated substantial scientific resources to maize research in several of the 11 producing countries covered in WCA. Maize in Nigeria has the largest scientific cadre equivalent to 77 FTE scientists. Some of these are university research staff who allocate part of their time to maize research.

The median programme size is 8–9 FTE scientists, which should be sufficient to get the job done for all small and most medium-sized producing countries unless the crop is produced in highly diverse agroecologies or unless changes in basic knowledge lead to a radical shift in the distribution of yield potential. In agricultural research, there are diminishing marginal returns to sampling from the same distribution when knowledge is stagnant or only increasing incrementally (Kislev, 1977). In other words, most crop improvement programmes are subject to economies of scale as we would not expect the desirable number of scientists in a programme to increase proportionally to rising production. Very large programmes will not have hundreds of scientists.

In contrast to other crops, the number of scientists engaged in all the maize improvement programmes in ESA is not a cause for concern. The nine programmes are all staffed by more than 12 FTE scientists, with Angola and Mozambique tied for the smallest programme. Even the smallest maize programmes in ESA have more scientists than the median-sized programme for 16 of the 19 other crops (Table 18.1).

A median programme size of 15 for wheat underscores the continuing commitment of governments to invest heavily in this import substitute that is grown on large farms, often with access to irrigation in Kenya, Zambia and Zimbabwe. Ethiopia, where wheat is grown by

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smallholders, is by far the largest wheat producer in SSA. A value of 11 for barley reflects the emphasis that Ethiopia places on agricultural research.

Pearl millet is at the other end of the human resource spectrum. Indeed, its largest country programme only has about 7 FTE scientists. With the exception of the largest-producing countries in West Africa, pearl millet is almost always a shared programme with other coarse cereals. Groundnut suffers a similar outcome (Table 18.1) and is often a member of a composite programme made up of pulses and/or oilseeds.

Saying something more conclusive about the data in Table 18.1 requires adjusting for the differences in the size of production across different countries. Attaining a critical mass of scientists is needed to make progress in large-producing countries and crossing a threshold size of production is required before resources should be committed to investing in crop improvement in very small-producing countries (Maredia and Eicher, 1995).

In Table 18.2, the size of production has been normalized across crops and countries by calculating research intensities that express FTE scientists as ratios from the perspectives of area, production and value of production. As anticipated, crops characterized by small areas and values of production are associated with higher estimated research intensities than those with very large areas, production levels and value of production.

The ranking of the crops in terms of research intensity varies somewhat across the three criteria in Table 18.2. Potato ranks high in research intensity on area but occupies a low position on production and value. Banana ranks high on area, low on production and high on value. However, there are more aspects in common than are different across the three criteria.

Table 18.2. Estimated research intensities by crop in SSA in 2010 from the perspectives of area, production and value of production.[a]

Area		Production		Value of production	
Crop	FTE scientists per million hectares of production	Crop	FTE scientists per million tonnes of production	Crop	FTE scientists per US$100 million of the crop
Chickpea	112.4	Lentil	89.1	Banana	25.2
Pigeonpea	64.2	Chickpea	83.6	Soybean	21.4
Potato	61.3	Soybean	45.6	Chickpea	18.4
Lentil	55.6	Bean	43.3	Pigeon pea	17.5
Banana	45.9	Field pea	31.4	Lentil	16.2
Soybean	44.0	Wheat	20.5	Field pea	14.0
Wheat	42.9	Faba bean	20.5	Wheat	13.7
Beans	32.5	Pigeonpea	20.3	Barley	12.8
Field pea	29.7	Barley	15.1	Maize (ESA)	8.5
Faba bean	25.3	Maize (ESA)	12.3	Sweetpotato	7.0
Rice	24.0	Cowpea	11.3	Faba bean	6.2
Barley	22.8	Rice	10.1	Beans	6.1
Sweetpotato	22.1	Maize (WCA)	8.1	Maize (WCA)	5.7
Maize (ESA)	16.5	Potato	6.5	Cowpea	5.3
Maize (WCA)	14.0	Groundnut	4.2	Rice	3.9
Cassava	12.6	Banana	4.2	Potato	3.4
Yam	10.6	Sweetpotato	3.6	Sorghum	2.2
Cowpea	6.6	Sorghum	2.9	Groundnut	1.4
Groundnut	5.3	Pearl millet	1.6	Cassava	1.2
Sorghum	2.5	Yam	1.0	Pearl millet	1.0
Pearl millet	1.4	Cassava	0.9	Yam	0.4

[a]All estimates are weighted averages of area in hectares, production in tonnes and value of production in total US$.

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In general, several pulses rank high in research intensity in all three criteria. The first five crops listed in the production column of Table 18.2 are all pulse crops with relatively small areas of production. The exceptions are soybean in Nigeria and pulses that are produced in Ethiopia, which has invested substantial scientific resources in its NARS in terms of the number of scientists. Bean's high ranking speaks to the stability of the Pan-African Bean Research Alliance (PABRA) – one of the regional crop improvement associations that survived a shrinking budget for international crop improvement research in the 1990s and early 2000s (Muthoni and Andrade, Chapter 8, this volume). Cowpea, which is the lowest ranking pulse in Table 18.2, is produced almost entirely in West Africa.

Turning to the cereals in Table 18.2, barley does well because of its location in Ethiopia, which has a large and regionally decentralized national programme at the Ethiopian Institute of Agricultural Research (EIAR). Rice also displays a research intensity estimate above 10 from the perspective of production. Potato has a leading position in roots and tubers because of its high market orientation and demand in East Africa.

Cassava, yams and pearl millet appear at the bottom of Table 18.2. Relative to their area, production and value of production, all three of these semi-subsistence food crops appear to be starved of research resources. In terms of area, groundnut and sorghum are also characterized by very low research intensities.

The estimated research intensities for pearl millet and sorghum in the arid and semi-arid tropics of India in Chapter 14 (this volume) are three to four times larger than those in Table 18.2 for the same crops in SSA. Apparently, higher research intensities associated with smaller country size are not sufficient to compensate for the lack of investment in agricultural research on these coarse cereals in West Africa.

These intercontinental differences would be even greater if educational attainment was factored into the estimation of research intensity. Nine of ten scientists in pearl millet and sorghum research in India have PhDs; only slightly more than one-third of the FTE scientists in SSA are PhD holders.

The disparities in research intensity between India and SSA are also notable in groundnut. Estimated research intensities are more than twice as high in India than in SSA. If smaller country programmes in ESA were not included, the difference between research intensities would be similar to those encountered in pearl millet and sorghum.

In contrast to pearl millet, sorghum and groundnut, rice's weighted average research intensity of 24 FTE scientists per million hectares of growing area in SSA is 10 to 12 times larger than what one typically finds for predominantly rainfed rice cultivation in South Asia (Chapter 13, this volume). Part of this difference is attributable to small-producing countries in SSA. Increasing urban demand and related policies that favour import substitution are other major contributors to the position of rice as the cereal with the highest research intensity in SSA in 2010.

Specific cases of resource deprivation can be identified by counting the incidence of falling below an arbitrary but seemingly reasonable threshold of critical mass. This lower bound threshold for large programmes exceeding 2 million tonnes of production is established at nine scientists (the median-size programme as shown in Table 18.1). Ten large-producing crop-by-country combinations fall below this minimum threshold: cassava in Benin, Côte d'Ivoire, Malawi and Mozambique; cowpea in Côte d'Ivoire and Guinea; groundnut in Nigeria; pearl millet in Niger and Nigeria; and sorghum in Nigeria. From the perspective of production, the estimated research intensity of these 10 crops is in the range of 0.2–2.0 and averages 1.0.

Building on the estimated research intensities in Table 18.2, it is useful to compare the actual allocations of FTE scientists with normative allocations calculated from a congruence rule. This states that research resources should be allocated in proportion to the value of production across commodities, if all other things are considered equal (Alston *et al.*, 1995). In priority setting, 2% of value of production is a common assumption because studies have shown that research investment proportional to agricultural gross domestic product (GDP) often exceeds 2% in developed countries (Walker *et al.*, 2006). In developing countries in SSA, the 2% criterion is rarely obtained (Beintema and Stads, 2011). In large countries, such as China and India, where economies of scale and size prevail, research investments in the order of 1% of agricultural GDP are commonplace.

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When comparing normative to actual allocations, we have assumed that 1% of the value of production is desirable for the size of research investment and that each scientist costs on average US$115,000 in purchasing-power parity (PPP) in 2010. The latter assumption is well within the range of comparable estimates in the ASTI (Agricultural Sciences and Technology Indicators) Initiative country studies. We also cap the maximum size of a crop-by-country programme at 80 FTE scientists, recognizing economies of size and scale in agricultural research. This admittedly arbitrarily imposed limit is slightly above the size of the largest programme – maize in Nigeria.

In order to achieve congruence or parity in research intensities across crops with a fixed budget, resources would have to be reassigned from the crops with positive estimates in Table 18.3 to the commodities with negative estimates. The sign and size of the estimates by crop are sensitive to our assumptions on a desirable target for research intensity, the cost of each FTE scientist and the limit on the size of the programme. The relative position of the crops in Table 18.3 will change somewhat as these assumptions vary but not as much as their numerical values. Assuming payoffs are the same – a very large and strong supposition – these more formal results reinforce the findings on research intensities in Table 18.2. Using the congruence rule to set priorities shows that research into cowpea, groundnut, pearl millet, sorghum and yams is under-invested in relative to other crops, from the perspective of the value of production.

Table 18.3. Comparing the actual allocation of FTE scientists in SSA to a normative allocation by crop programme.

	Simple average in FTE scientists		
Crop	Actual allocation	Normative allocation[a]	Difference
Banana	42.0	11.1	30.9
Wheat	17.5	8.5	9.0
Chickpea	13.5	4.9	8.6
Maize (ESA)	27.0	21.3	5.8
Barley	11.1	5.8	5.3
Pigeonpea	7.8	3.0	4.8
Soybean	3.9	1.2	2.7
Lentil	3.6	1.5	2.1
Field pea	6.9	5.2	1.7
Sweetpotato	6.5	6.3	0.3
Faba bean	7.8	8.4	–0.6
Beans	8.7	9.5	–0.9
Cowpea	4.5	5.6	–1.2
Maize (WCA)	12.7	14.7	–2.0
Rice	9.6	16.6	–7.0
Potato	7.6	14.7	–7.1
Groundnut	3.4	16.4	–13.0
Sorghum	6.6	20.3	–13.7
Pearl millet	4.1	27.8	–23.8
Cassava	8.2	32.1	–24.0
Yams	7.0	47.3	–40.4

[a]Assumes a research intensity of 1% of value of crop production, a cost per FTE scientist of US$115,000 and a maximum programme size of 80 FTE scientists.

Differences in scientific strength over time

Results on differences in scientific strength over time are mixed. Between 1998 and 2010 more programmes have gained scientists than have lost researchers but, because of rising production, estimates of research intensity have not improved and have even declined for the majority of the 65 country programmes with information available to carry out paired comparisons. Before addressing changes over time, we briefly examine the results of previous estimates of scientific staff strength in 1998 for SSA (Walker, Chapter 5, this volume).

1. Nigeria stood out as a country with consistently low researcher intensity. Indeed, Nigerian farmers appeared to be afflicted by some of the lowest readings on researcher intensity ever estimated anywhere in the world. Mean readings of the ratio of FTE scientists to million tonnes of production were 0.1 for cassava, 0.5 for sorghum, 1.7 for rice, 1.8 for pearl millet and 2.6 for maize, which benefited from some private sector participation in research. Nigeria ranked among the lowest in researcher intensity in each of the five commodity groups to which it was a major contributor. The country also figured prominently when the performance indicators for these same crops were aggregated.

2. Ethiopia, Kenya, South Africa and Sudan were characterized by a higher investment in scientific staff than other countries in the 1998 data set. This behaviour was reflected in positive and statistically significant estimated country

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coefficients in an additive effects model regressing total scientists years on production, crops and countries.

3. Researcher intensity was lower in cassava than in other crops even when the relatively inferior output value of cassava was factored into the calculation. Rice and sorghum also had lower than expected research intensities, although not as extreme as cassava.

4. Estimates of researcher intensity declined exponentially as the size of production increased from under 50,000 tonnes to more than 5 million tonnes.

Data are available for a before-and-after analysis of the changes in scientific capacity for 65 matching crop-by-country observations that feature eight of the continuing crops (Table 18.4). Thirty of the 65 programmes had fewer FTE scientists in 2010 than in 1998. Among the 35 programmes that gained staff, two observations were unduly influential in the results: maize programmes in Nigeria and Zimbabwe both experienced increases that were equivalent to more than 40 FTE scientists.

Some of this change is undoubtedly real, but some may be attributable to an underestimation of scientific capacity in 1998, e.g. maize in Nigeria included substantially more university researchers in 2010 than in 1998. Excluding maize in Nigeria and Zimbabwe, the mean scientific strength in 1998 was 8.4 FTE scientists compared to 9.7 in 2010, resulting in a positive but statistically insignificant change at the 0.05 level. The median programme also gained 1.3 FTE scientists as the difference between the two time periods was normally distributed. Overall, these results suggest a marginal increase in scientific capacity.

Cassava appears in Table 18.4 as the largest loser of scientific capacity. Maize in ESA, potato, rice and wheat were the biggest gainers.

These gains in staff were not sufficient to translate into increased research intensity in most crops. The net decline in research intensity was about 1.7 scientists per million tonnes of production, which suggests that growth in production outstripped the smaller positive changes in staffing. Maize and wheat in ESA were the only crop categories that accrued substantial gains in researcher intensity (Table 18.4).[2]

A first-difference comparison of the bulk of the overlapping crop-by-country observations is presented in Fig. 18.1. For reasons of scale, three high-end outliers are excluded: maize in Kenya that had very large values in 1998 and 2010, and maize in Nigeria and Zimbabwe that had high values in 2010.

A small majority of the 62 remaining observations increased their numbers of scientific staff between the two periods. One of these was cassava in Nigeria which added about 6 scientists. Notably, we also see that several of the largest commodity programmes on the right-hand side of Fig. 18.1 could not sustain their staff strength. These were mainly concentrated in cassava-growing programmes. For example, Benin, Guinea and Tanzania downsized to only 2–3 scientists per programme.

For a few maize programmes in WCA, the numbers of scientific staff also declined over time. But these declines were more than compensated for by Nigeria's dramatic increase in

Table 18.4. Differences in estimated FTE scientists and research intensities between 1998 and 2010 by crop based on 65 paired comparisons.

Crop	Mean FTE scientists	Median FTE scientists	Mean research intensity	Paired observations
Bean[a]	–0.6	–0.8	1.3	8
Cassava	–2.4	–2.3	–4.7	14
Maize (ESA)	10.8	7.0	3.9	9
Maize (WCA)	4.3	–3.3	–32.4	9
Pearl millet	–1.1	–1.0	–0.9	5
Potato	6.9	3.6	–7.9	4
Rice	4.3	3.8	–4.3	6
Sorghum	1.9	1.4	–10.3	6
Wheat	7.3	8.5	110.9	4

[a]For bean, the definition of scientists applies only to breeders.

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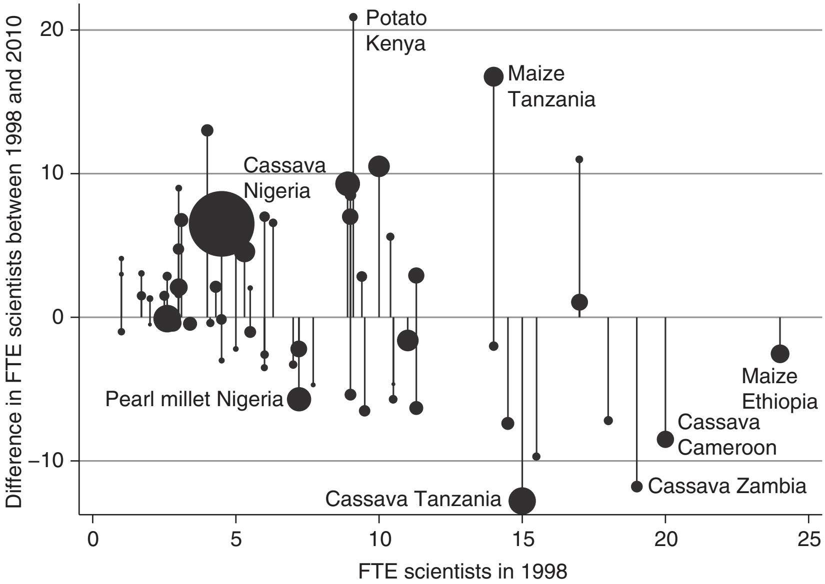

Fig. 18.1. Change in scientific staff strength in food crop improvement programmes between 1998 and 2010. The size of the circles reflects the size of production value in 2010. Note that Nigeria's observation for cassava is the largest circle in the bubble graph. (Source: DIIVA SY Database.)

scientific staff, discussed earlier. Overall, the data presented in Fig. 18.1 convey the message that larger crop improvement programmes may be highly susceptible to downsizing in times of financial crisis or when donor support ends.

Other aspects of scientific capacity: age, education and area of specialization

The problem of scientific capacity in NARS in West Africa is not only a problem of numbers but also of age. About 65% of the scientists working on groundnut, pearl millet and sorghum in the five project countries in West Africa were over 50 in 2010 (Ndjeunga *et al.*, Chapter 7, this volume).

Scientists engaged in crop improvement across WCA appear to be more highly educated than their ESA counterparts, with around 2.6 PhD holders per programme. But in future, an estimated lower number of BSc holders in WCA is a cause for concern because fewer younger scientists will be available to be mentored by, and capitalize on the experience of, older scientists (Table 18.5).

The incidence of scientists with PhDs and MSc qualifications is encouraging (Table 18.5). Only 24 of the 135 programmes did not have a PhD presence. Only four programmes had neither a PhD nor an MSc scientist involved directly in their research. More than half of the programmes have at least 1.0 FTE PhD scientist working in research. For the most part, all crops and most countries have at least one programme supported by several PhDs and MScs. Eritrea was the exception among the 30 countries in the Diffusion and Impact of Improved Varieties in Africa (DIIVA) Project. Nonetheless, it was still possible to find programmes, such as cassava in Tanzania, that were severely understaffed both numerically and educationally in 2010.

Staff stability is a primary ingredient for a recipe of sustained output from investing in crop improvement research (Eicher, 1995). Even with increasing participatory varietal selection (PVS) and marker-assisted selection (MAS) it can take, on average, about 10 years from parental crossing to progeny release in the same country. PVS is increasingly becoming a reality in rice and beans among the food crops in the DIIVA Project. MAS is still rare and newsworthy in SSA.

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Table 18.5. Educational level of scientists in crop improvement programs by region in SSA.

	Number of observations	Mean number of FTE scientists by educational level			
		PhD	MSc	BSc	Total
ESA	65	1.51	3.20	2.33	7.03
WCA	70	2.61	2.84	1.66	7.12
Total	135	2.08	3.01	1.98	7.07

It has been applied to facilitate varietal development in only a few successful cases, such as sorghum in the Sudan (ICRISAT, 2013). The DIIVA Project sought to collect information on the duration of varietal generation, selection and testing. However, reliable data over time on this aspect of crop improvement performance were not forthcoming, so we cannot say whether the gestation period of new improved or modern varieties (MVs) is shortening or staying the same. We can say, though, that instability in scientific staffing levels within crop improvement programmes can severely curtail their potential. Full potential will only be reached if the routine work of varietal selection and testing takes place season after season and year after year.

Estimates on experience levels within the same area of research suggest that many scientific staff have been able to work on the same crop for an extended period of time. For example, the 289 NARS rice scientists had worked on rice improvement for an average of 12.25 years as of 2010 (Diagne *et al*., Chapter 10, this volume). Scientists with 10 or more years' experience made up the majority of staff in five of the ten bean programmes in ESA (Muthoni and Andrade, Chapter 8, this volume). This level of experience was not anticipated because only about one scientist in six was older than 50 in 2010 across the ten bean improvement programmes.

Estimates on the allocation of scientists across specialized areas of crop improvement are presented in Tables 18.6 and 18.7 on two aspects: crop type and strength of scientific resources. We expect that relative allocations across areas of specialization will vary substantially across cereals, grain legumes, and roots and tubers. Root and tuber programmes that are based on vegetatively propagated material and on clonal selection are hypothesized to be characterized by a more diverse area allocation than cereals and grain legumes, which typically are more heavily concentrated in classical plant breeding. It was expected that increasing human resources would be accompanied by less concentration in plant breeding and agronomy, which are conventionally viewed as the core disciplinary areas of crop improvement research.

These expectations are largely confirmed in Tables 18.6 and 18.7, although the differences among programmes based on generalized crop orientation as well as small versus large programmes are not as obvious as anticipated. With regard to crop type, the main distinction focuses on roots and tubers on one hand, and cereals and grain legumes on the other. Root and tuber crop programmes invest considerably less in plant breeding and more in the biotechnological areas of molecular biology and tissue culture than cereal and grain legume programmes. With the exception of postharvest research, the other research areas are surprisingly similar across the generalized crop types. The emphases in entomology, pathology, agronomy and social science are not markedly different across the three groups of crops.

Three other findings in Table 18.6 warrant comment. First, molecular biology only accounts for 3.4% of the mean resources across the 150 programmes in the database. This level of investment is not significantly different from tissue culture, which has been a staple area in root and tuber crop improvement since the 1970s. The 3.4% is equivalent to only 40 FTE scientists, 17 of whom work on banana in Uganda. Second, the level of social science involvement in crop improvement work is much higher than 5%, which was expected. Third, postharvest work is concentrated on maize and cassava in Nigeria.

It was also anticipated that smaller programmes would have a higher concentration of disciplinary resources vis-à-vis larger programmes.

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Table 18.6. Relative allocation of scientists by disciplinary specialization across roots and tubers, grain legumes and cereals in SSA in 2010 (%).

Broad areas of crop improvement work	Root and tuber crops (5)a	Grain legumes (8)	Cereals (7)	All 20 crops
Plant breeding including germplasm conservation	21.8	45.8	44.39	39.6
Plant pathology	8.3	10.9	7.80	9.2
Molecular biology and genetic engineering	11.4	0.5	1.22	3.4
Tissue culture	11.9	0.1	0.40	3.0
Entomology and nematology	5.4	6.1	7.38	6.3
Agronomy, weed science and seed production	25.2	24.6	23.68	24.4
Social science	8.7	10.3	9.36	9.6
Postharvest and food science	5.0	0.6	4.55	3.6
Other areas including soil science	1.2	0.2	0.20	0.6

[a]Numbers in parentheses refer to the number of observations in each crop category.

Table 18.7. Relative allocation of scientists by disciplinary specialization across programme-size quartiles in SSA in 2010 (%).

Broad areas of crop improvement work	Quartile 1	Quartile 2	Quartile 3	Quartile 4
Plant pathology and virology	5.9	7.6	11.19	7.1
Molecular biology and genetic engineering	1.0	2.3	2.44	3.7
Tissue culture	3.2	3.9	2.74	3.3
Entomology and nematology	3.9	7.4	11.01	5.4
Agronomy, weed science and seed production	24.3	20.4	15.51	20.5
Seed production	7.9	8.4	6.38	10.3
Social science	2.8	6.6	12.90	8.6
Postharvest and food science	1.6	3.4	5.1	5.3
Total FTE scientists	63.1	137.9	292.0	796.1

Indeed, the largest programmes in quartile 4 in Table 18.7 display a more even disciplinary allocation pattern across disciplines than the smallest programmes in quartile 1, but the differences are milder than expected. On average, even the smallest programmes from the perspective of total scientists invest about half of their resources in disciplines other than plant breeding. Nevertheless, the smallest programmes invest relatively few resources in molecular biology, entomology, social science and postharvest research compared to programmes in the quartiles with higher relative allocations. By contrast, the relative research allocations to tissue culture, pathology, agronomy and seed production do not vary systematically by size of the programme. This lack of response to programme size suggests that these areas are viewed as essential services for crop improvement.

The term ‘essential’ should not convey the notion that all programmes are active in these areas. Fifty of the 150 programmes do not have any representation in pathology, which historically has been one of the most productive areas in plant breeding in screening for varietal resistance and tolerance to economically important plant diseases. Investment in entomology in grain legumes was also lower than expected given the potential importance of damage from insect pests.

Comparing the disciplinary allocations in crop improvement programmes in SSA to those documented in South Asia in Chapters 13 and 14 suggests one similarity and two contrasts. Like the national programmes in SSA, biotechnology accounted for less than 5% of the total FTE scientists engaged in crop improvement

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by crop in both Chapters 13 and 14. However, rice research in South Asia is heavily concentrated in plant breeding and genetics (Chapter 13, this volume). A second contrast focuses on the role of pathology and entomology in dryland crop research. They figure more prominently in India than in SSA where agronomy and its related disciplines (see Table 18.6) loom larger (Chapter 14, this volume).

Revisiting the hypotheses about FTE scientists

Seven input-related hypotheses were put forth in Chapter 3. Two of these positively stated hypotheses were rejected from the empirical data on FTE scientists generated in the DIIVA Project. Most importantly, disparities in research intensities across regions and crops *were* substantial. Relative to their size of regional production, national crop improvement programmes in ESA had invested more in scientific capacity than comparable programmes in WCA. Concerns about scientific capacity in national programmes in West Africa reflect not only a problem of relative numbers but also of scientist age. About 65% of the scientists working on sorghum, pearl millet and groundnut in the five project countries in West Africa were older than 50 in 2010. Moreover, a lower incidence in BSc-holders in crop improvement research in WCA is a cause for concern because fewer younger scientists are available for mentoring by older, experienced scientists.

Of the 20 crops, cassava, yams and pearl millet consistently ranked at the bottom on research intensity. Relative to their area, production and value of production, all three of these semi-subsistence food crops appear to be losing the race for research resources. In terms of harvested area, groundnut and sorghum in West Africa are also characterized by very low research intensities.

Drought in SSA was the cause of 17 of the 100 most damaging natural disasters that occurred worldwide in the 20th century (CRED, 2014). The highest incidence of these drought-induced production shortfalls occurred in the arid and dry semi-arid tropics where pearl millet, sorghum, groundnut and cowpea are the major food crops. That these crops still lag far behind others in estimated research intensity is one of the most disappointing findings of the DIIVA Project. Without greater investments in agricultural research, the cost of relief efforts will continue to rise in the Sahel and the Horn of Africa as rural populations increase and climatic change becomes an increasing reality.

With the exception of root and tuber crops in a few country programmes, evidence for investments in biotechnology was also less visible than expected. The DIIVA studies in SSA do not show that *the disciplinary distribution of FTE scientists in crop improvement reflects an increasing capacity in biotechnology*. A similar finding was obtained at the national level in South Asia as addressed in Chapters 13 and 14: not much evidence was encountered for the increasing salience of biotechnology.

Results on the differences in scientific strength over time echoed the findings of Beintema and Stads (2006). Between 1998 and 2010, slightly more programmes have gained than have lost researchers. However, because of rising levels of crop production, mainly attributed to area expansion, estimates of research intensity have not increased and, indeed, have even declined for most of the 65 programmes that have information available to carry out paired comparisons. Therefore, we cannot state that *research intensities in national food crop improvement programmes are increasing*. We find solid support, however, for the hypothesis that *the number of FTE scientists in national food crop improvement programmes in SSA is increasing* because the gainers employed more scientists than the losers who reduced staff. The paired comparisons over time also suggest that larger public sector crop improvement programmes might be highly susceptible to downsizing in times of financial crisis or when donor support ends.

Evidence for *rising private-sector participation in research in the genetic improvement of cereal hybrids* divided along regional lines. By far, the largest increase in scientific capacity has occurred in maize across ESA, thanks largely to favourable government policies, such as relaxation on the government's exclusive right on the production of breeders' seed and the dynamism of the private sector in this region. In contrast, private-sector participation in the generation and distribution of cereal hybrids in WCA has stagnated in many large-producing countries. At best, participation seems to have stagnated or, at worst, regressed compared to what was documented in

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Manyong *et al*. (2003). Unlocking constraints to greater private-sector participation in hybrid cereal production West Africa is as relevant today as it was in the late 1990s.

Some support was also uncovered for the hypothesis that *university participation in research is becoming increasingly visible from a small base.* Support was most transparent for maize improvement in Nigeria. For all crops other than maize, however, research scientists came overwhelmingly from the public-sector NARS.

Varietal Output: Released Varieties

As discussed in Chapter 3, varietal output is synonymous with released varieties broadly defined. 'Output' refers to the expansion that can be attributed to genetic improvement in the potential availability of genotypes for cultivation. Attribution is measured from a with-and-without perspective, i.e. the difference in potential availability from genetic improvement and what would have been available without an investment in plant breeding. Therefore, released varieties include many cultivars that are not officially notified including so-called informal introductions, escapes and private-sector materials that may not be officially notified but which are available to farmers. Restricting varietal releases to government-notified materials will severely understate output from crop genetic improvement that is potentially available for adoption (Alene *et al*., Chapter 6, and De Groote *et al*., Chapter 11, this volume).

Findings on varietal output in 1998

In the 1998 Initiative, most CGIAR (Consultative Group on International Agricultural Research) participants were successful in assembling valid release data for almost all countries, supplemented by information on so-called informal releases of suspected improved varieties. For maize in ESA, release was equated to varietal availability in the market in the late 1990s because of heavy private-sector participation in seed production and distribution. In spite of the inherent difficulties in inferring varietal output from varietal release, such data present an historical benchmark that, once consolidated carefully, can provide a firm foundation for updates over time.

In the pooled analysis of varietal release covering 1965–1998 reported in Chapter 5, we found:

1. Across all crops, annual releases increased at an accelerating rate from the 1960s to the late 1990s.
2. Political instability adversely affected varietal output in some crops in key countries in the 1990s, such as potatoes in Rwanda.
3. Some crops were characterized by high numbers of releases prior to 1975. The crop improvement programmes of the CGIAR were most likely a force that contributed to offsetting differences in initial advantage in research endowments because most CG Centers reached their full potential to generate varietal output in the 1990s.
4. Across the eight food crops in the study, the higher and more stable release rate in wheat was anticipated. In contrast, the very low release intensity for cassava was unanticipated.
5. Release profiles were often punctuated by bursts of activity sandwiched between long periods of inactivity.

Varietal output by 2010

Updating the database for the continuing crops and assembling fresh historical data on varietal output for the new crops in Table 18.8 broadly confirms the five findings cited above from the analysis of the 1998 data.

The historical data on varietal output across the 20 crops contain 3594 entries. About 90% of these have information on the year of release. The undated entries are associated with modern materials that were judged to be available to farmers or are located in countries that do not maintain a formal release registry. Many of these come from the International Institute of Tropical Agriculture (IITA; Alene *et al*., Chapter 6, this volume) and are listed as 'informal' releases. Participants were encouraged to add escapes and other adopted materials perceived as modern to the release database so that information on their identity and characteristics was available (Walker, 2010). Most, but not all, of the dated entries in Table 18.8 imply official release.

Maize leads all crops with over 1000 entries in the cultivar-release database. Rice is second

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Table 18.8. Counting the number of cultivars in the varietal release database by crop in SSA from before 1970 to 2011.[a]

Crop	Number of countries	Number of cultivars in the varietal release data	Number of released cultivars with year of release information	Output intensity (total releases/ million ha) in 2009
Banana	1	13	6	14
Barley	2	41	41	42
Bean	9	250	232	100
Cassava	17	355	207	32
Chickpea	2	27	26	108
Cowpea	17	200	157	17
Faba bean	2	28	28	46
Field pea	1	26	26	113
Groundnut	10	140	137	22
Lentil	3	15	14	158
Maize (ESA)	8	692	664	47
Maize (WCA)	11	330	271	33
Pearl millet	5	121	120	9
Pigeonpea	3	17	17	46
Potato	5	117	117	190
Rice	11	436	428	64
Sorghum	8	174	180	11
Soybean	15	201	156	170
Sweetpotato	5	89	89	60
Wheat	5	244	243	146
Yam	8	78	35	17
Total/average	148	3594	3194	68

[a]This count also includes the same cultivar released in different countries under a different name.

with over 400. Both maize in ESA and rice have had access to multiple institutional sources of modern genetic materials.

A simple index of output intensity can also be constructed for comparative analysis across crops. In Table 18.8, output intensity is expressed in terms of total releases per million hectares (ha) in 2009. Similar to research intensity, we expected the results to show that less extensively grown crops are characterized by higher levels of output intensity. Indeed, this expectation was confirmed for lentil, soybean, potato and wheat, all of which were associated with strong market demand. Additionally, during the mid-20th century both wheat and potato in SSA benefited from a strong programme of genetic improvement thanks to the Rockefeller Program in Mexico. The genetic base for many released varieties in SSA came from that early work.

At the other end of the spectrum, five crops fell under the low threshold of less than 20 cultivars released per million hectares of harvested area in 2009. Low research intensities in pearl millet and sorghum have translated into low output intensities. The same finding applies to countries producing cowpea. Relatively few varieties have been released recently (Alene and Mwalughali, 2012). A low estimated research intensity for banana is derived from the observation that hybridization is still difficult. More than all other crops in Table 18.8, low output intensity in yams is attributed to historically negligible levels of research investment.

The parity between the output intensity of cassava and maize in WCA is perhaps the most interesting finding in Table 18.8. The total number of releases and their total harvested area are almost identical for the two crops. The example of cassava suggests that low research intensity does not preordain mediocre performance in output.

Varietal output over time

Tracking cultivar release over five decades supports the anticipated finding that varietal output has been increasing over time. About 45% of the

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3194 dated entries in Table 18.8 were released since 2000 (Table 18.9). The mid-point for data release was 1998. Decade by decade, the incidence of release has steadily increased over time.

Not all crops fit the pattern of a steady rise in varietal output over time. In ESA, varietal output rose exponentially in maize between the 1990s and the 2000s because of surging private-sector releases. Groundnut displays a flat trajectory in output for more than four decades and then output rises abruptly from 2000. Unfortunately, this increase in releases is confined mainly to smaller-producing countries in ESA. Meanwhile, WCA is still associated with stagnation in the incidence of released varieties, e.g. varietal output in cowpea has declined sharply from its peak in the 1990s.

Three cereals have also not been able to maintain an increase in varietal production. Varietal output in pearl millet peaked in the 1980s. Meanwhile, varietal performance in sorghum tapered off in the 2000s. Constricting resources both internationally and nationally have played a role in limiting varietal output in pearl millet and sorghum in West Africa prior to the rise in food prices in 2008.

In spite of the widespread introduction of the New Rice for Africa (NERICA) varieties starting in the mid-1990s in most rice-growing countries in SSA, varietal release also slowed in rice in the 2000s. Political instability and civil war in Côte d'Ivoire and Sierra Leone severely curtailed releases caused by the closure of several rice research stations. With the exception of Senegal, West Africa shows a downturn in releases in the 2000s compared to the 1980s and 1990s. Even in Guinea, where varietal output exceeded 100 varieties in the 1980s and 1990s, rice releases are becoming increasingly rare.

Releases in the post-1998 period are described in Table 18.10. Five crops have been able to maintain a simple average annual release rate of at least one variety released per programme. Fuelled by Kenya's and Zambia's high production – with over 100 varieties released since 1998, mostly by the private sector – maize in ESA easily tops the list at five varieties released per annum per programme. Seven of the eight maize-growing countries released more than 29 varieties during this recent period.

In general, releases were unevenly distributed across countries within each crop. Thirty country programmes reported no releases, and 45% of the 148 crop–country programmes released fewer than five varieties during the 12-year period. The country with the most releases often accounted for more than one-third of the total releases and, in the case of yams in Côte d'Ivoire, the vast majority of total releases. In contrast with cowpea, none of the 17 countries in the data set released more than ten varieties in the 10-year period.

Wheat's position near the top of Table 18.10 in weighted annual release rate was anticipated. Ethiopia is by far the largest producer and recently has been prolific in varietal release, which explains why the weighted annual rate is substantially higher than the simple annual rate. The release performance of the smaller wheat-growing countries of Kenya, Tanzania, Zambia and Zimbabwe has slowed somewhat recently.

Table 18.9. The frequency of cultivar release by decade by crop in SSA.

	Released varieties and hybrids by decade				
Crop	Pre-1970	1970s	1980s	1990s	2000s[a]
Banana	0	0	0	0	6
Barley	0	3	3	4	31
Bean	1	6	22	73	130
Cassava	0	2	31	61	113
Chickpea	0	3	2	9	12
Cowpea	3	8	49	65	32
Faba bean	0	3	2	8	15
Field pea	0	2	2	10	12
Groundnut	20	23	25	21	48
Lentil	0	0	4	5	5
Maize (ESA)	7	10	34	159	455
Maize (WCA)	12	25	75	76	82
Pearl millet	1	7	46	28	38
Pigeonpea	0	0	3	2	12
Potato	3	18	29	24	43
Rice	27	53	133	138	77
Sorghum	2	25	36	63	54
Soybean	2	13	32	52	57
Sweetpotato	0	0	9	20	60
Wheat	20	43	43	40	97
Yam	0	0	0	5	30
Total	98	244	580	863	1409

[a]The end year for the period is either 2009, 2010 or 2011, depending on the crop.

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Table 18.10. Performance in varietal release from 1999 to 2011 by crop improvement programme.

		Annual release rate		Total releases[b]	
Crop[a]	Total releases	Simple	Weighted by area	Maximum	Minimum
Maize (ESA)	485	5.1	5.1	143	0
Wheat	106	1.8	4.0	53	5
Barley	31	1.3	2.2	28	3
Bean	148	1.4	1.4	27	8
Maize (WCA)	91	0.6	1.4	37	0
Yam	30	0.3	1.3	23	0
Cassava	128	0.6	1.2	20	0
Sweetpotato	66	1.1	1.1	28	1
Faba bean	15	0.6	1.0	14	1
Field pea	12	1.0	1.0	12	12
Chickpea	12	0.5	1.0	12	0
Potato	47	0.8	0.8	24	1
Sorghum	58	0.6	0.6	30	0
Banana	6	0.5	0.5	6	6
Rice	77	0.6	0.5	23	0
Cowpea	34	0.2	0.5	8	0
Soybean	61	0.3	0.4	16	0
Pearl Millet	39	0.7	0.4	17	1
Pigeonpea	12	0.3	0.4	6	2
Groundnut	46	0.4	0.4	9	0
Lentil	5	0.1	0.3	4	0

[a]The crops are ordered by annual release rate weighted by area in column 4. [b]The maximum and minimum refer to country programmes over the release period and not individual years.

Ethiopia's sustained efforts in varietal release also explain barley's ranking near the top of Table 18.10. Moreover, a decentralized regional research emphasis has reinforced release activities in Ethiopia. The buoyancy and productivity of the aforementioned PABRA network – the umbrella organization that oversees three regional genetic networks in SSA – contributed heavily to the release performance of beans in the recent period. Sweetpotato programmes also released varieties at a rate of more than 1% per annum. The fruition of a longstanding CIP (International Potato Center)-supported breeding programme in Mozambique made a substantial contribution to this output.

At the lower end of Table 18.10, there are the same crops that displayed lagging levels of human resources investment in genetic improvement programmes. The estimated release rate for cowpea, groundnut, pearl millet and sorghum indicate one release per country programme every 3–5 years.

The low position of soybean for the recent period in Table 18.10 is a surprise for an expanding commercial crop from a very small production base in most countries. Such countries are probably following a cost-effective strategy of capitalizing on finished materials from other tropical and semi-tropical countries, especially Brazil and Argentina. Nevertheless, those varieties should still appear in the varietal registries maintained by countries in SSA.

Between one-fifth and one-quarter of the 146 crop-by-country observations were characterized by more releases in the 1980s than in the 2000s. These observations are identified in Fig. 18.2 by the number of releases in the 1980s and the change in releases between the two periods. Results imply declining productivity in crop improvement varietal output over time. Some of these observations were casualties of civil war during the 1990s and early 2000s.

Civil war, as a major explanation for falling varietal output, applies to rice in Sierra Leone, potato in Rwanda and rice in Côte d'Ivoire. For other observations, the explanation for their presence in Fig. 18.2 seems to be country or region specific. Most of the observations come

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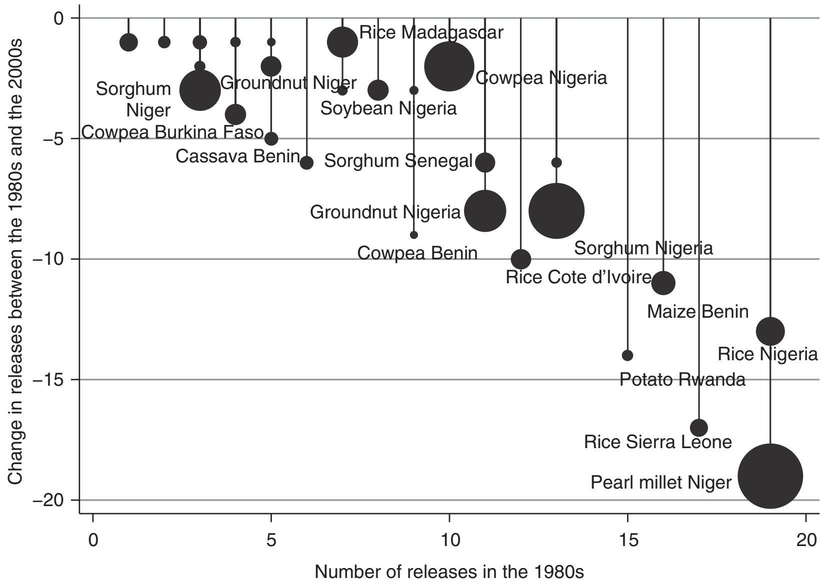

Fig. 18.2. Crop-by-country observations with more releases in the 1980s than in the 2000s.

from West Africa. As the balloons in Fig. 18.2 show, Nigeria accounts for a large share of total area of all the observations. Cowpea, groundnut, pearl millet, rice and sorghum are well represented in Fig. 18.2. With the exception of rice, these crops finished at the bottom of Table 18.2 in estimated research intensities in 2010.

The historical record on CGIAR contributions to varietal output

The commodity centres of the CGIAR can leverage varietal output through the direct distribution of elite material and their finished varieties, progenies for selection, and parents for direct crossing by NARS. About 43% of the varieties released since 1980 in Table 18.9, or some 1500 varieties, are related to the work of the CGIAR.

The CGIAR contribution is greater than 40% for the majority of crops in Table 18.11. In several cases, two or more CG Centers contribute to varietal releases of the same crop. Notable examples of joint contributions include ICRISAT and ICARDA (International Center for Agricultural Research in Dry Areas) for chickpea; IITA and CIMMYT (Centro Internacional de Mejoramiento de Maiz y Trigo) for maize in WCA; and AfricaRice, the International Rice Research Institute (IRRI), and IITA for rice (before IITA closed its rice programme).

The six crops below the 40% contribution level in Table 18.11 are suitable candidates for discussion about why their estimates are lower than those of other crops. Barley and field pea are primarily grown in Ethiopia and are researched in a strong NARS setting where the crops have considerable genetic diversity as a locus of domestication.

Other institutional suppliers play a large part in the reported estimates for banana and maize in ESA. The Honduras Foundation for Agricultural Research (FHIA) has contributed significantly to the improvement of banana in SSA, especially in finding cultivars resistant to *Fusarium* wilt – a soil-borne fungal disease – in the brewing, cooking and dessert types of banana.

Between 1958 and 2010, the private sector – without direct participation from other institutions – was responsible for 56% of maize releases in ESA (De Groote *et al.*, 2011). In Chapter 11, the CGIAR is credited with a 23% share of improved maize variety releases, together with NARS and the private sector. This estimate is substantially higher than what is currently shown in the DIIVA database but even a 23% contribution to varietal output is low compared to estimates for other crops in Table 18.11.[3] Historically, the public

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Table 18.11. The contribution of IARCs of the CGIAR to varietal output in SSA 1980–2011.

Crop	Number of dated released varieties related to CGIAR activity	Share of CGIAR-related varieties to total dated releases (%)
Chickpea	23	95.8
Lentil	13	86.7
Pigeonpea	14	82.4
Potato	72	75.0
Yam	26	74.3
Maize (WCA)	173	74.2
Cassava	143	68.1
Sweetpotato	59	66.3
Cowpea	88	57.5
Rice	179	51.4
Soybean	69	48.9
Wheat[a]	81	45.0
Groundnut	41	43.6
Pearl millet	45	40.2
Faba bean	10	40.0
Bean	88	39.1
Maize (ESA)	171	22.8
Sorghum	38	24.8
Barley	8	21.1
Banana	1	16.7
Field pea	4	16.7

[a]The share estimate for wheat is understated because data collected in the smaller-producing countries did not contain information on the institutional source of genetic material since 2000.

sector's contribution to varietal research declines when the private sector becomes established in cross-pollinated crops that can be readily hybridized (Fuglie and Walker, 2001). The private sector is well established in Kenya, Zambia and Zimbabwe where hybrids dominate the market.

The 39% estimate for beans approaches the average level of CGIAR contribution in Table 18.11. Multiple smaller institutional providers have added a global perspective 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 Collaborative Research Support Program (CRSP (recently renamed Innovation Laboratory)) in the USA, Institute of Horticultural Plant Breeding (IVT) in the Netherlands, Escuela Agricola Panamericana Zamorano (EAP) in Honduras, Centro Agronómico Tropical de Investigación y Enseñanza (CATIE) in Costa Rica, National Vegetable Research Station (NVRS)–Wellsbourne Project in the UK and the Tokachi Agricultural Experiment Station in Japan. Genetic materials from the genebank in Beltsville, Maryland, USA, have also figured prominently in several varietal releases.

The Institut de Recherches Agronomiques Tropicales (IRAT) now Agricultural Research for Development (CIRAD) has played a large role in generating materials that have resulted in varietal change in several food crops in West Africa. CIRAD also works on non-staple crops and has historically placed less emphasis on genetic enhancement than has CGIAR. But the relatively low level of CGIAR contribution to sorghum releases in West Africa is not related to strong NARs in centres of diversity or to alternative suppliers of material. The overly aggressive pursuit of a breeding strategy focusing on shorter statured, photoperiod-insensitive material is a plausible explanation of why ICRISAT's contribution is not higher, especially in West Africa (Ndjeunga *et al.*, 2012). Farmers strongly prefer tall, photoperiod-sensitive Guinean types of sorghum.

The commodity centres in the CGIAR mostly date from the late 1960s and the early 1970s. We would expect to see a rising contribution from CG-related materials over time from 1980. That expectation is confirmed here, between the 1980s and the 1990s, as the CGIAR share in varietal output rose from 42–46% (Table 18.12). But, contrary to our expectation, the role of the CGIAR declined in the 2000s compared to the 1990s.[4] This decline could be attributed to the funding crisis in the mid-to-late 1990s and early 2000s when the exchange of germplasm and genetic materials became more constricted. The increasing rate of private sector releases in maize in ESA, especially in Kenya and Zambia with more than 100 releases since 2000, has directly had a dampening effect on the CGIAR share. When maize in ESA is omitted, the revised estimate in the second row of Table 18.12 shows a plateauing of the CGIAR contribution at about 56% in the 1990s and 2000s.

Revisiting the hypotheses about varietal output

Our findings broadly support the hypothesis that the stock of released and non-released improved

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Table 18.12. IARC-related percentage share estimates over time with and without maize in ESA.

Basis for the estimation	1980s	1990s	2000s	Average share
All crops and regions in the database	41.5	45.8	41.0	42.8
Without maize in ESA in the estimation	43.6	55.9	56.2	51.9

varieties that are potentially available to farmers for use is increasing over time. Relative to the levels of their production, however, pearl millet, sorghum, groundnut, cowpea and yam lag behind other crops in output of improved varieties.

Looking into the future, we expect that the upward trend in varietal output will continue. The food price crisis in 2008 has led to greater funding for agricultural development in general and agricultural research in particular. Although slow in coming, greater regional harmonization of plant regulations should also stimulate varietal output at the national level.

The evidence is also positive but not as robust for the hypothesis that *output stability is increasing over time because peaks and troughs in varietal generation are less evident than in the recent past*. Although seemingly improving, stability in varietal releases documented in Chapters 6–12 for SSA pales in comparison to what is described in Chapters 13 and 14 for South Asia. Indeed, the hallmark of the release profiles in South Asia has been the stability of varietal release over time. For example, the All-India Coordinated Sorghum Improvement Program of ICAR released an improved variety or hybrid at either the central or state level annually from 1961 to 2010 in all but three years (Chapter 14, this volume). For the five major dryland crops produced in peninsular India, a minimum of 20 releases were registered in each of the five decades from 1960. By way of contrast, rice improvement in Nigeria was the most stable food-crop research programme in the DIIVA varietal release database. Between 1954 and 2005, 57 improved varieties in the public sector FARO (Federal Agricultural Research Oryzae) series were released for cultivation. But, during that period that spanned more than five decades, varieties were released in only 23 years. Multi-year gaps in release were common. The stability of varietal release in crop improvement programmes in South Asia speaks for their durable funding, scientific staffing and research organization.

The last hypothesis in Chapter 3 on varietal output was not supported to the extent that was expected. In general, we did not find persuasive evidence that *varietal output reflected the evolution of plant breeding over time or a lower IARC presence*. The incidence of direct crossing was less than expected in most crops in the DIIVA Project release database. Even large NARS programmes, such as rice in Nigeria, still rely heavily on introduced finished varieties, although they generated and released varieties from direct crosses in-country as early as the mid-1980s. Releases from landraces continue to figure prominently in a sizeable minority of programmes in the 2000s.

IARC presence and contributions seem to be as relevant now as they were in the past. In contrast, the role of IRRI-related germplasm is diminishing in the varietal output of rainfed rice research programmes in South Asia described in Chapter 13. A reduction in IARC influence testifies to the increasing maturity of those programmes that were documented globally by Evenson and Gollin (2003). That this global finding about the maturity of national plant breeding programmes still does not apply to countries in SSA is troubling.

Notes

[1] Several chapters in this volume also report on the scientific strength of relevant CG Centers. Trends in staff strength in crop improvement are described in Walker *et al*. (2014) for specific IARCs. In general, the number of scientists in crop improvement programmes declined sharply in the CGIAR from the mid-1990s through to the early 2000s.

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[2] Declining production in a crop can lead to rising research intensity. But among these observations, only wheat in Zimbabwe seems to demonstrate increasing research intensity attributed to secularly decreasing output.
[3] Recently, CIMMYT and IITA have partnered in the release of more than 100 varieties in SSA as part of the Drought Tolerance for Maize in Africa Initiative.
[4] This could be viewed as progress: NARS and the private sector are taking on additional responsibilities, freeing the CGIAR to focus on basic research.

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