19 Varietal Adoption, Outcomes and Impact

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Parallel to the preceding chapter, we synthesize the results of Chapters 6–17 here. The focus is on outcomes and impacts. Outcomes centre on varietal adoption and turnover; impacts refer to changes in on-farm productivity, poverty and food security. Hypotheses from Chapter 3 are revisited at the end of each thematic section.

Varietal Adoption

By crop

The area-weighted grand mean adoption level of improved varieties in Sub-Sharan Africa (SSA) across the 20 crops in the project is 35% (Table 19.1). Two-thirds of the crop entries in Table 19.1 fall below the mean estimate. Starting at the bottom of the table, the limited uptake for improved field pea, which is produced primarily in Ethiopia, is not surprising. Internationally and nationally, field pea is arguably the crop species in Table 19.1 that has had the smallest amount of resources allocated to its improvement.

In contrast, both chickpea and lentil have benefited from international agricultural research in the CGIAR (Consultative Group on International Agricultural Research) since the early-to-mid-1970s. Although progress has been made, adoption of improved cultivars of both crops is concentrated in small pockets of production regions in Ethiopia where extension programmes have been active (Yigezu *et al*., 2012a). This apparent location specificity is typical of pulse crops, but it is surprising in light of improved lentil varieties that have reportedly significantly heavier yields than their local counterparts.

Adoption levels of faba bean and chickpea are buoyed by a reportedly higher penetration of improved varieties in the Sudan. Indeed, chickpea in the Sudan is the only crop-by-country observation to have been at full adoption level in 2010, albeit on a very small area of 21,000 ha

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Table 19.1. Adoption of modern varieties (MVs) of food crops in sub-Saharan Africa in 2010.

Crop	Country observations	Total area (ha)	Adopted area (ha)	MVs (%)
Soybean	14	1,185,306	1,041,923	89.7
Maize (WCA)	11	9,972,479	6,556,762	65.7
Wheat	1	1,453,820	850,121	62.5
Pigeonpea	3	365,901	182,452	49.9
Maize (ESA)	9	14,695,862	6,470,405	44.0
Cassava	17	11,035,995	4,376,237	39.7
Rice	19	6,787,043	2,582,317	38.0
Potato	5	615,737	211,772	34.4
Barley	2	970,720	317,597	32.7
Yam	8	4,673,300	1,409,309	30.2
Groundnut	10	6,356,963	1,854,543	29.2
Bean	9	2,497,209	723,544	29.0
Sorghum	8	17,965,926	4,927,345	27.4
Cowpea	18	11,471,533	3,117,621	27.2
Pearl millet	5	14,089,940	2,552,121	18.1
Chickpea	3	249,632	37,438	15.0
Faba bean	2	614,606	85,806	14.0
Lentils	1	94,946	9,874	10.4
Sweetpotato	5	1,478,086	102,143	6.9
Banana	1	915,877	556,784	6.2
Field pea	1	230,749	3,461	1.5
Total/weighted average	152	107,721,630	37,969,577	35.25

(Yigezu *et al.*, 2012a). Meanwhile, Ethiopia harvests more than 0.5 million ha of faba bean, yet the perceived adoption of improved cultivars is very low at 3.5%.

Cooking, dessert and beer bananas in Uganda are also characterized by low adoption. This finding is not that surprising. Stimulating varietal change in a clonally propagated crop – and one that is not an annual – is a challenging proposition anywhere in the world. A focus on disease resistance is necessary, but entrenched consumption preferences are potentially major constraints to adoption, which may be only partial in the best of circumstances (Kagezi *et al.*, 2012).

The National Banana Research Program of the National Agricultural Research Organization (NARO) in Uganda also faces the challenge that elite clones for evaluation were only introduced on farms from 1991. NARO has made a considerable commitment to biotechnology in order to exploit to the fullest the opportunity for varietal change and has mobilized several international partners in the supply of elite clonal materials. The potential for harnessing biotechnology in Uganda for regional varietal change is a recurring theme that has been reported in the Diffusion and Impact of Improved Varieties in Africa (DIIVA) Project for other clonally propagated crops such as cassava (Alene and Mwalughali, 2012).

Groundnut, sorghum and pearl millet also fall below the adoption average of 35% in Table 19.1. They are produced extensively in the Sahelian, Sudian and Guinean zones of West Africa. All three crops share the same poor country-specific outcomes in terms of adoption: negligible diffusion of improved varieties in Burkina Faso and no recorded adoption in Senegal where varietal output has paled in comparison to the robust performance in Mali (Ndjeunga *et al.*, 2012). The uptake of improved groundnut varieties is moderately high in several smaller East African countries but that diffusion does not compensate for the lack of adoption in West Africa.

Scientists in West Africa have also gone down some blind alleys. For example, sorghum breeding overemphasized *Caudatum* types that could not compete with the dominant Guinean materials prevalent in the region (Ndjeunga *et al*., 2012). Photoperiod-insensitive, short-duration *Caudatum* materials were high yielding but they were susceptible to pests, disease and bird damage and did not measure up to the consumption expectations of semi-subsistence producers who also consume a sizeable share of their output.

Additionally, groundnut crop improvement scientists in the Francophone countries have to compete with old improved cultivars grown prior to independence. Groundnut variety 55-437, released some 40 years ago, is still the dominant variety in Senegal and even in Anglophone Nigeria (Ndjeunga *et al*., 2012). In Mali, groundnut varieties 47-10 and 28-206 released in the 1950s are the most popular cultivars.

In spite of the dearth of investment in the improvement of these crops in West Africa as well as scientists' ageing profiles, some progress has occurred that has been below the radar for some time. SOSAT C88 – an improved, ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) related short-duration pearl millet variety released in 1988 in Mali and Niger, and in 2000 in Nigeria – lays claim to an area slightly exceeding 1 million hectares. This variety is grown in a larger area than any of the over 1000 improved adopted cultivars listed in the DIIVA database. Varietal change in groundnut in East Africa, especially in Uganda, is another success story that was stimulated by an impressive partnership between NARO, ICRISAT and the Peanut CRSP (Collaborative Research Support Program) of the United States Agency for International Development (USAID).

Barley, cowpea and yams also appear in the lower half of Table 19.1. Starting from a very low base of 11% in 1998, the uptake of improved barley varieties in Ethiopia has slowly but steadily increased over time. Both improved food and malting barleys have contributed substantially to modern variety (MV) adoption (Yigezu *et al.*, 2012b).

Cowpea adoption outcomes are dominated by the performance of crop improvement research in Niger and Nigeria, which, when combined, have a harvested area of over 8 million hectares. Niger is characterized by a harsh production environment and variable scientific capacity, featuring donor instability. These conditions have resulted in an adoption estimate of 9% in Niger that has kept cowpea from entering the top half of Table 19.1.

According to FAO production data, yams have the highest calculated value of production of any crop, including cassava and maize, in SSA. This fact seems incredible because maize and cassava are usually considered the staple food crops in SSA but an absence of crop improvement research targeted on a species as spatially concentrated as yams does not seem that surprising. The 30% adoption estimate for yams in Table 19.1 is attributed to a 75% outcome for improved varieties in Côte d'Ivoire, the second largest producer in West Africa (Alene *et al.*, Chapter 6, this volume). C18 is the prevalent variety. Following its introduction in Côte d'Ivoire in 1992, C18 expanded rapidly, covering large areas of yam cultivation where it sometimes represents 100% of the area cultivated in *Dioscorea alata* – otherwise known as 'yellow' or 'water' yam — one of six economically important yam species. C18 is known for making tasty yellow porridge.

Both beans and sweetpotato partially owe their position in the lower half of Table 19.1 to this study's stance on excluding released local landraces from the definition of MVs. The adoption level for beans would rise to 50% with a broadening of this definition, whereas the adoption level of sweetpotato would triple to 24%.

Among grain legumes in Table 19.1, improved varieties of beans rank third in adoption outcomes. Bean MVs are characterized by a substantially higher uptake in Ethiopia than MVs for any other grain legume in the DIIVA Project, presumably because Ethiopia has developed a vibrant export industry for haricot beans.

In 1984, a regional breeding programme was established in the Great Lakes region of SSA. It focused on breeding for resistance to bean pests and diseases in conditions of low and declining soil fertility typical of small rural household production. To meet this challenge, the Pan-African Bean Research Alliance (PABRA) was launched as a CIAT project in 1996. It now consists of three regional genetic improvement networks – the Eastern and Central Africa Bean Research Network (ECABREN), the Southern Africa Bean Research Network (SABRN) and the West and Central Africa Bean Research Network

(WECABREN) – and encompasses 29 countries in SSA. PABRA has a record of sustainability and growth that is matched only by a few other regional International Agricultural Research Center (IARC)-related crop improvement networks (Lynam, 2010).

The sustainability of the PABRA umbrella network has strongly influenced these positive outcomes for adoption in a crop that is often characterized by niche specificity in terms of production conditions and market preferences. Identification of improved bean varieties in farmers' fields is an onerous undertaking. With a few notable exceptions, improved bean varieties are believed to account for only small chunks of area in most countries, thereby making the validation of such spatially fragmented expert opinion a difficult task.

In the 1970s and 1980s, not much research was conducted on sweetpotato in SSA. Sweetpotato owes its rather modest position in Table 19.1 to a stable and sustained breeding effort in Uganda and Mozambique (Labarta, 2012). Interest in orange-fleshed sweetpotato for its high beta-carotene content has also helped to stimulate and marshal investment in what was once a relatively neglected secondary food crop in SSA. The adoption of improved varieties in Table 19.1 is about equally split between white- and orange-fleshed varieties.

Adoption of potato MVs are at the mean level in Table 19.1. Given the crop's market orientation and rapidly increasing growth rate in SSA over the past two decades, an adoption level that approaches the mean value across all crops could not be termed superior performance. Following a longer-term CIP (International Potato Center) presence, Malawi has only recently released improved varieties that are now in the very early phase of adoption. The greater uptake of improved clones in Ethiopia and Kenya has not compensated for the sharp downturn in the use of improved materials in Rwanda since the 1994 Genocide which destroyed not only the potato improvement programme in Ruhengeri – the hub of CIP activities in the Great Lakes Region (Rueda *et al.*, 1996) – but also devastated an effective seed programme. Although potato is a priority food crop, recovery in Rwanda has been slow for improved clones, which were believed to be close to full adoption in the early 1990s, prior to civil war.

Cassava is perhaps the most surprising member of the set of seven crops with above-average adoption in Table 19.1. In spite of low levels of research intensity documented earlier, the performance of cassava crop improvement has been solid and steady with regard to adoption outcomes. The majority of the countries included in this study have substantially higher levels of uptake of improved varieties now than in the late 1990s (Alene and Mwalughali, 2012). A strategy that has emphasized high yield combined with disease resistance in a mostly sweet, rather than bitter, background seems to have yielded good dividends in many countries. Additionally, donors have actively supported public-sector and non-governmental organization (NGO) programmes to propagate and widely distribute improved planting materials.

The location of pigeonpea in the top half of Table 19.1 was also expected. All three study countries in East Africa have a commercial demand for higher yielding medium-duration types that are well adapted to bi-modal seasonal rainfall in Kenya, Malawi and Tanzania (Simtowe and Mausch, 2012).

Maize in ESA benefited from the large number of released varieties stimulated by liberalization policies and private-sector investment in maize breeding. As discussed in the previous section, varietal output borders on prodigious in some countries, such as Zambia, which has enacted policies strongly favouring maize production. Excellent performance in Zambia and Malawi has not, however, compensated for the lack of tangible progress in Angola and Mozambique. In Angola, the dominant released cultivars only account for about 5% of the area planted and date from the mid-to-late 1960s prior to independence.

Adoption outcomes seem to be at a moderately high level for rice, which is grown in well-defined agroecological settings throughout SSA. Aggregate adoption levels still depend heavily on what happens in Nigeria and Madagascar, two countries that together account for more than half of the rice-growing area in the 14 countries studied that had data available on this aspect. Aggregate adoption levels also hinge on adoption outcomes in the rainfed lowlands and the uplands. The aggregate level is also sensitive to adoption outcomes in Guinea, which arguably has released more varieties with less ensuing adoption than any other of the 152 crop-by-country national adoption observations. Recent gains in adoption in several countries appear to have been driven by a positive response from farmers to the New Rice for Africa (NERICA) varieties (Diagne *et al.*, 2012). More than any other crop, rice was negatively affected by the decision to define MVs from 1970 – an earlier starting date in 1960 would have led to higher adoption levels but this points to the continued use of very old varieties.

Maize in West and Central Africa (WCA) secures the second spot in adoption performance in Table 19.1. Improved maize varieties in WCA gained more ground in adoption than any other crop in SSA between 1998 and 2010. And these gains were accomplished without significant private sector input (Alene and Mwalughali, 2012). Most of these gains were recorded via the adoption of open-pollinated varieties (OPVs). Some of these are getting older and undoubtedly not all farmers renew seed in a timely fashion, raising questions about the sensitivity of our definition of improved varieties. Factoring in seed renewal rates would lead to a lower adoption estimate but the uptake of improved maize varieties would still be very impressive (Alene *et al.*, 2009).

Wheat topped the crop adoption table in 1998. The increasing transition in area from durum to spring bread wheat was one of the factors leading to the higher adoption of improved varieties in Ethiopia – by far the largest producer in SSA. Wheat would probably occupy a higher position in Table 19.1 if reliable data on adoption had been collected for Kenya, Tanzania, Zambia and Zimbabwe. These countries were at the level of full adoption of wheat MVs in 1998. Assuming full adoption in 2010 is eminently plausible because wheat in these four countries is mainly produced in large farms with irrigation. The inclusion of these four countries results in a rise in the adoption estimate to 70%, which is still substantially less than soybean in Table 19.1. The limited penetration of improved durum varieties into farmers' fields in Ethiopia is a major constraint to full adoption of wheat high-yielding varieties (HYVs) in SSA.

Soybean ranks first in our crop adoption table. Soybean is a new crop characterized by strong market demand. Genetic materials are mostly imported from abroad; sufficient time has not elapsed to allow many local landrace materials to develop. Although improved soybean adoption levels are not surprising, their varietal age is – as discussed in the next section. Given soybeans' scope for global expansion, the crop seems to be taking its time in finding a home in farmers' fields in SSA. Nigeria still harvests more soybean area than the other 12 countries in Table 19.1 combined.

By country

Aside from the Central African Republic's second place ranking – attributed to the adoption of rice MVs – there are relatively few counterintuitive findings in the adoption estimate by country rankings (Table 19.2). One is the relatively

Table 19.2. Weighted area adoption levels by country in SSA in 2010.

Country	MV adoption (%)	Number of crop observations
Zimbabwe	92	4
Central African Republic	72	1
Cameroon	68	6
Zambia	67	6
Kenya	63	8
Gambia	56	1
Côte d'Ivoire	55	6
Ghana	53	6
Benin	52	6
Malawi	47	8
Senegal	45	6
Sudan	41	4
Nigeria	41	9
DR Congo	36	6
Madagascar	35	1
Mali	35	6
Ethiopia	33	9
Uganda	33	11
Tanzania	32	10
Guinea	29	5
Togo	22	6
Rwanda	21	4
Angola	17	2
Sierra Leone	16	1
Burundi	14	4
Niger	14	4
Eritrea	13	2
Burkina Faso	13	6
Mozambique	13	5

high placing of the DR Congo in achieving an above-average adoption outcome across all crops in spite of stagnating institutional and economic development.

The five countries at the bottom of Table 19.2 all share a weighted adoption estimate below 15%. Burkina Faso is the outlier with a high adoption performance in maize and rice. Burkina Faso is also the first adopter of Bt (*Bacillus thuringiensis*) cotton varieties aside from South Africa. Burkina Faso's position is attributed to negligible adoption of groundnut, sorghum and pearl millet MVs. Other countries, like Angola, Mozambique and Niger in the lower five, have uniformly low rates of adoption of improved cultivars across all crops.

Optimism is warranted about the prospects for enhancing adoption in countries such as Ethiopia, Mali and Uganda that are now characterized by average levels for SSA as a whole. However, attaining a moderately high adoption rate of 50% as a hypothetical development goal by 2020 will be a daunting challenge, unless adoption prospects improve markedly for countries in the bottom half of the table.

By cultivar

About 87% of the MV adopted area is associated with detailed data containing regional and cultivar-specific information. The other 13% refers to aggregate adoption only at the national level.

The regional and cultivar-specific database accounts for slightly over 33 million hectares. Adopted area is attributed to named (where they are available) and unnamed varieties. Unnamed varieties are aggregated into a category called 'other'.[1]

There are 1173 named releases in the cultivar-specific adoption database. They account for 98% of the 33 million hectares described above. The size distribution of area planted with these varieties is heavily skewed, consistent with previous findings in the 1998 Initiative for maize in ESA, potato, rice and wheat. Most of the varieties are grown on small areas; the median-sized variety is cultivated on only about 7000 hectares, whereas 250 entries were adopted on less than 1000 hectares. The 75th percentile of the cumulative distribution occurs at about 22,000 hectares. Only 76 varieties exceed 100,000 hectares of adopted area.

Few, if any, of these varieties could be called mega varietie that cover tens of millions of hectares, such as the rice variety Swarna that is extensively grown in South Asia (Chapter 13, this volume). The most extensively grown variety is SOSAT-C88 – the leading pearl millet cultivar in Nigeria and the second-ranking improved variety in Mali. SOSAT-C88 was one of the subjects of the impact assessment in the DIIVA Project (Ndjeunga *et al.*, 2011).

Most of the more extensively grown or more economically valuable improved varieties are concentrated in a small subset of crops and countries. Value of production estimates complement harvested area in describing the economic importance of adopted varieties.[2] By either criterion, the top 100 varieties account for about 60–65% of the total adopted area and value of production of all adopted varieties.

On the basis of a value criterion, the share of cereals in the top 100 falls and the share of vegetatively propagated crops rises dramatically. According to FAO production data, 1 hectare of cooking banana, yams or potato can be worth the equivalent of 25–30 hectares of sorghum and pearl millet in value. Therefore, it is not surprising to see relatively small areas of improved clones of these crops claim a larger share in the top 100, when value of production is the criterion. Indeed, a small majority of the varieties in the top-value 100 are vegetatively propagated.

The top ten-ranking varieties are listed in Table 19.3. Cereals dominate the area classification, but only pearl millet cultivar SOSAT C88 makes it into the top ten when the categorization is based on value. Under either criterion, Nigeria contributes more varieties than all other countries combined. Aspects of several of these economically important varieties are described in the next section on spill-overs.

Spill-overs in adoption

Although the history of crop improvement research is marked by spill-overs in adoption in SSA, spill-overs are not the first thing that comes to mind when thinking of adoption outcomes in the harsh rainfed production environments of Africa. Adaptability is restricted by low fertility

Table 19.3. Top-ranked varieties by commodity and country by area and value of production.

	Area			Value		
Rank	Name	Crop	Country	Name	Crop	Country
1	SOSAT C88	Pearl millet	Nigeria	TMS 30572 (Nicass 1)	Cassava	Nigeria
2	Wad Ahmed	Sorghum	Sudan	C18	Yams	Cote d'Ivoire
3	Oba 98	Maize	Nigeria	TDr 89/02660	Yams	Nigeria
4	TMS 30572 (Nicass 1)	Cassava	Nigeria	TMS 4(2)1425 (Nicass 2)	Cassava	Nigeria
5	ICSV 111	Sorghum	Nigeria	NR 8082 (Nicass 14)	Cassava	Nigeria
6	Kubsa	Bread wheat	Ethiopia	TDr 89/02602	Yams	Nigeria
7	ICSV 400	Sorghum	Nigeria	TDr 89/02665	Yams	Nigeria
8	Suwan 1-SR	Maize	Nigeria	SOSAT C88	Pearl millet	Nigeria
9	Tabat	Sorghum	Sudan	Sadisa (91/203)	Cassava	DR Congo
10	C18	Yams	Côte d'Ivoire	Afisiafi (TMS 30572)	Cassava	Ghana

in environments characterized by seemingly high levels of location specificity.

Positive evidence for spill-over outcomes was well documented in the colonial era in SSA. For example, in collaboration with the British, scientists in Sierra Leone had been working to increase regional rice production in the difficult mangrove agroecology since 1934. The locus of their activities – curtailed in the 1990s because of the civil war – was the Rokupr Rice Research Station. Before independence this was known as the West African Rice Research Institute and its mandate was to promote spill-overs. Several released ROK rice varieties became popular, not only in Sierra Leone but also in Guinea and Guinea Bissau. They have also been the subject of adoption studies and impact assessments (Adesina and Zinnah, 1993; Edwin and Masters, 1998).

The case of the high-yielding, late-maturing maize hybrid SR 52 – the world's first triple-cross hybrid grown commercially – released in the early 1960s in present-day Zimbabwe is a well-known example of varietal output that generated benefits to neighbouring countries in Southern Africa (Eicher, 1995). A lesser-known example after independence focused on late-blight-resistant potato cultivars in the Great Lakes Region of East Africa. In the early 1970s, three late-blight-resistant varieties – at the time, recently released from Mexico – were imported into Uganda and Kenya via the Rockefeller Foundation. Although these varieties never laid claim to much area in Mexico, they quickly became popular in several smaller countries in East Africa. Before the 1994 Genocide in Rwanda, Sangema was the dominant variety in Rwanda and was arguably the most economically important in the ESA region in the 1970s and early 1980s. Even today Rosita, a synonym for Sangema, is the prevailing potato variety in Malawi and Mozambique.

Confirming the potential for spill-overs, the products of older regional crop improvement programmes are still visible in their respective geographical sphere of influence. The Armani Regional Station now in Tanzania but at one time covering all of East Africa has been the location for research that has led to long-term spillovers since the 1950s and 1960s in cassava and sweetpotato materials as progenitors and in a few cases as finished elite clones. Researchers at Armani developed the sweetpotato variety known as Tanzania in Uganda and Rwanda, as Sinama in Tanzania, as Enaironi in Kenya, as Kenya in Malawi, and as ADMARC in central Mozambique, and Chingovwa in Zambia (Labarta, 2012). In the five countries included in the CIP study (Labarta, Chapter 9, this volume), this variety is estimated to be cultivated on an area approaching 200,000 hectares, equivalent to 13% of the total sweetpotato area. (Because of its age, Tanzania is not considered in the set of improved varieties.) It combines high dry matter, a marked preference in East Africa, with a strong background of virus resistance in the Great Lakes region.

In many of the study crops within the DIIVA Project, researchers were able to identify more recent examples of spill-overs, where investing in varietal improvement in one country has benefited neighbouring countries or other countries in SSA. Spill-overs in adoption are not as common as spill-overs in releases, but they are very visible when they occur.

IITA researchers described in detail the occurrences of spill-overs in adoption for all five of their mandated crops in the DIIVA Project (Alene and Mwalughali, 2012). In cassava, TMS 30573 occupies 17.8% of the area in Nigeria, 17.5% in Uganda, 7% in Benin and 3.2% in Guinea. Though not officially released, the same clone is also being grown extensively in Kenya where it covers 24% of the cassava area and, to a much lesser extent, is produced in Côte d'Ivoire.

In cowpea, popular multi-country varieties are: IT82E-32 covering 23% of the total cowpea area in Ghana, 11% in Benin and 2% in Cameroon; followed by VITA-7, accounting for 22% of total cowpea area in Guinea and 13% in Democratic Republic of Congo (DR Congo) (Alene and Mwalughali, 2012). Adoption of variety IT81D-1137 is estimated at 17% in DR Congo and 14% in Benin. These varieties are attractive to farmers because they feature high yield potential, disease tolerance and short duration.

In maize, Obatanpa – derived from quality protein maize (QPM) materials and TZEE-Y – fit the description of spill-over varieties that have crossed over the borders of several countries in WCA (Alene and Mwalughali, 2012). Two improved soybean varieties are also widely cultivated in the region. Firstly, TG× 1448-2E – a shattering and frog-eye, leaf-spot resistant IITA-bred variety – is sown on more than 60% of soybean area in Nigeria and on more than 20% of harvested area in Cameroon and Ghana. TG× 1835-10E – another IITA-developed variety desired for its early maturity and resistance to soybean rust, pod shattering and lodging – dominates soybean areas in Uganda (50%) and covers 26% of soybean area in Kenya as well as 6% in Nigeria.

In yams, examples of large spill-over effects are harder to find but a few improved cultivars are found in two countries. Florido is planted in Benin and Togo; TDr 89/02665 is propagated in Ghana and Nigeria in 5–10% of the total planted area.

Groundnut seems to be the exception to the finding that the prevalence of wide adaptability and spill-over varieties is less common in ESA than in WCA. In four of the five groundnut study countries in the ESA region, rosette-resistant ICGV-SM 90704 and drought-tolerant ICGV 83708 ranked first or second in the adoption of improved varieties.

Finally, in rice, NERICA 1 is presently grown in five of the 12 producing countries with cultivar-specific information in the DIIVA adoption database. Earlier, BG 90-2 from Sri Lanka was a commonly introduced cultivar that was released by the majority of rice-producing countries in West Africa and later became popular in several countries.

The incidence of spill-over varieties appears to be higher in West Africa than in East Africa. The Sahelian, Sudanian and Guinean zones of West Africa cut across broad swathes of several countries. This makes for more homogeneous agroecological conditions going from west to east across countries than from north to south within the same country. The incidence and size of spill-overs also varies by crop: lower in beans and higher in potatoes in East Africa. In ESA, spill-over events in maize were not as large, although they were probably underestimated because of incomplete and low quality data. SC 627 is a variety that scores well on wider adaptation and is grown extensively in Tanzania and Malawi (De Groote *et al.*, 2011).

In West Africa, spill-overs vary from crop to crop. Spill-over varieties are readily visible in pearl millet and groundnut but less so in sorghum. The pearl millet variety SOSAT C88 mentioned previously has been adopted in four West African countries. Similarly, the groundnut variety Fleur 11 is also spreading in West Africa from Senegal to Mali and Niger (Ndjeunga *et al.*, 2011).

The emphasis on spill-over varieties in this subsection does not detract from the empirical fact that the varieties selected and used solely within a country are still likely to contribute far more to total adopted area in SSA than multi-country varieties. Moreover, as pointed out earlier in this section, none of the identified spill-over varieties can yet be called mega-varieties. The moderate incidence of well-identified spill-over varieties serves as a reminder that small NARS can still reap some benefits from national and international research. A stable crop improvement presence in the region can generate returns that far exceed national benefits for the investing country.

IARC-related adoption

Most IARCs have been heavy contributors to the varietal change that has taken place in their mandated crops in SSA (Table 19.4); about 22% of the crop area harvested is in IARC-related genetic materials. The relative importance of those materials approaches two-thirds of total area in improved varieties.

The crops in Table 19.4 are ordered by the difference between their estimated share in varietal output and adoption. It is interesting to see sorghum, pearl millet and groundnut at the head of this table because they lag behind in overall adoption. Released varieties of these crops may have had somewhat limited acceptance by farmers (Table 19.1) but IARC-related cultivars have had better adoption outcomes than most in a difficult rainfed production environment.

The mean weighted difference between the CGIAR's adoption and release shares is 20%. The crops towards the bottom of Table 19.4 are relatively new to crop improvement research in the CGIAR so we did not anticipate that they would have had high shares of IARC-partnered adoption.

Perhaps more than any other international non-CG institution and in any crop in the DIIVA Project, CIRAD (Institut de Recherches Agronomiques Tropicales – IRAT) has had a marked impact on the adoption of rice MVs in several countries of Francophone Africa, including Madagascar. This important institutional connection is a plausible explanation of why rice does not rank higher in Table 19.4. Likewise, the smallish negative value of maize in ESA could be attributed to the late start by CIMMYT (the International Center for the Improvement of Maize and Wheat) in the region and to alternative suppliers in the burgeoning private sector.

Comparing adoption levels between 2010 and 1998

The 1998 benchmark provides a basis for carrying out a before and after comparison of the level of varietal adoption for the ten continuing crops in the DIIVA Project (Table 19.5).

Table 19.4. The contribution of the CG Centers to MV adoption in SSA in 2010.

	Adoption			Release	
Crop	Estimated adoption (%)	IARC-Related (%)	Share IARC (%)	Share IARC (%)	Difference between adoption and release shares (%)
Sorghum	27.4	20.6	75.0	24.8	50.2
Pearl millet	18.1	15.7	86.6	40.2	46.4
Groundnut	29.2	25.0	85.8	43.6	42.2
Bean	29.0	23.5	81.0	39.1	41.9
Wheat	58.5	37.7	64.5	45.0	19.5
Banana	6.2	2.2	34.9	16.7	18.2
Potato	34.4	31.2	90.8	75.0	15.8
Sweetpotato	6.9	5.6	81.3	66.3	15.0
Cassava	39.7	32.7	82.5	68.1	14.4
Soybean	87.9	55.6	63.2	48.9	14.3
Lentil	10.4	10.4	100.0	86.7	13.3
Cowpea	27.2	18.1	66.7	57.5	9.2
Maize (WCA)	65.7	53.0	80.6	74.2	6.4
Chickpea	15.0	15.0	100.0	95.8	4.2
Barley	32.7	7.5	23.0	21.1	1.9
Pigeonpea	49.9	41.8	83.9	82.4	1.5
Rice	38.0	19.2	50.6	51.4	–0.8
Maize (ESA)	44.0	12.9	29.4	30.3	–0.9
Field pea	1.5	0.0	0	16.7	–16.7
Yam	30.2	15.1	50.0	74.3	–24.3
Faba bean	14.0	0.5	3.7	40.0	–36.3
Weighted average[a]	35.25	23	65.6	45.5	20.0

[a]Weighted by total area, except the share in adoption estimates that are weighted by total adopted area in each crop.

Table 19.5. Change in MV adoption between 1998 and 2010 in ten food crops of SSA.

Crop	Number of paired observations	1998 Area (ha)	1998 MV adoption (%)	2010 Area (ha)	2010 MV adoption (%)	Relative importance in 2010 (% area coverage of paired observations)
Barley	1	897,360	11.0	913,863	33.8	86
Bean	6	1,738,000	14.6	1,903,964	35.1	45
Cassava	15	8,777,800	21.0	10,033,995	42.0	81
Groundnut	3	496,517	12.6	724,019	56.7	7
Maize	19	18,566,300	25.6	24,366,088	52.8	91
Pearl millet	1	1,285,540	22.0	1,520,440	31.1	9
Potatoes	4	353,852	49.2	569,921	37.1	60
Rice	7	3,639,110	48.4	3,787,146	36.5	44
Sorghum	4	12,711,129	19.3	13,354,489	32.4	58
Wheat	1	1,330,000	56.0	1,453,820	63.5	84
Total/weighted average	61	49,795,608	25.0	58,627,745	43.9	55

On average, the 61 observations represent about 55% of the area of the crops grown in SSA. Coverage is adequate in eight of the ten crops to draw inferences about varietal change between 1998 and 2010. Coverage is too scanty to say anything definitive about progress in varietal uptake in groundnut and pearl millet.

Two important empirical facts emerge from Table 19.5. First, the average level of varietal adoption was 25% in 1998. Second, and more importantly, average MV adoption increased at a rate equivalent to a linear annual gain of 1.45 percentage points over the 13-year period to almost 44%.

With the exception of rice and potatoes, all crops experienced an expansion in the use of MVs. Uptake was especially robust in barley, beans, cassava and maize, with adoption levels doubling during the period.

The before and after data points for the primary staples, maize and cassava, are arrayed in Fig. 19.1. Maize in the DR Congo was the only crop-by-country observation to experience a steep decline in the estimated adoption rate between 1998 and 2010. Gains in the uptake of maize hybrids were significant in Zambia and Malawi. Hybrids also played an important role in Ethiopia. Increases in the West African countries and in Tanzania and Uganda were almost entirely fuelled by the spread of improved OPVs. In general, the cassava-growing countries were characterized by lower adoption levels in 1998 than the maize-producing countries; but, aside from Tanzania, every cassava-producing country displayed a propensity for the greater uptake of improved clones in 2010 than in 1998.

The difference in adoption between the two periods is negatively associated with the magnitude of adoption in 1998. Countries that commenced with levels of adoption equal to, or below, 40% tended to realize more gains in adoption. Those that started with moderately high rates of adoption of improved varieties were hard pressed to achieve even more positive outcomes in adoption. We expect this type of behaviour when a country approaches full adoption but not when it is at a moderate to high level of MV acceptance such as improved maize cultivars in Burkina Faso, Ghana and Kenya in 1998.

Lack of progress in countries with already moderately high rates of adoption indicates the existence of marginal production regions where MVs do not compete favourably with traditional varieties on a few important characteristics. It will be interesting to see if the new entrants in the moderate-to-high adoption group in Fig. 19.1 will be able to consolidate and expand on their gains.

Comparable before and after data on the remaining crops in Table 19.5 are presented in Fig. 19.2. Many relatively small-producing countries made relatively large gains in the adoption of beans and groundnut. Sorghum in the Sudan was the largest crop-by-country combination to register appreciable gains in adoption.

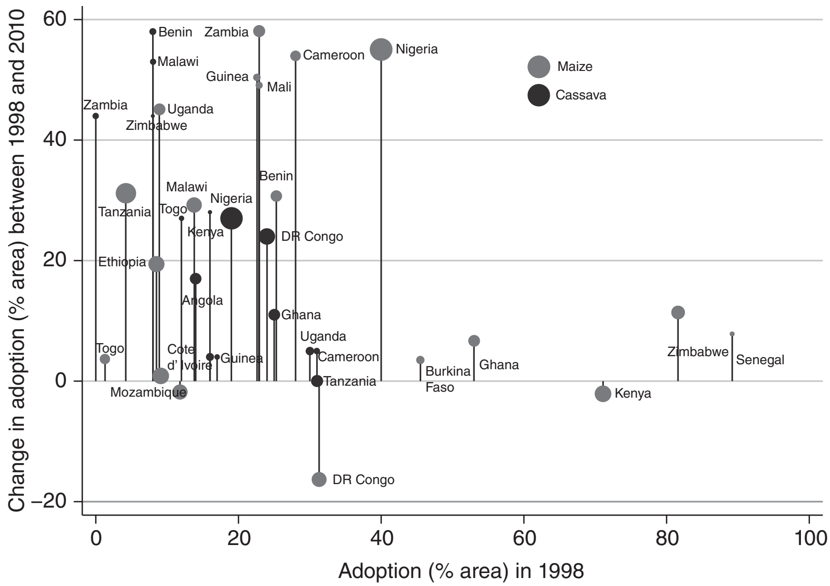

Fig. 19.1. Change in the estimated level of adoption of improved maize and cassava varieties between 1998 and 2010 (balloons in the droplines are weighted by area in 2010).

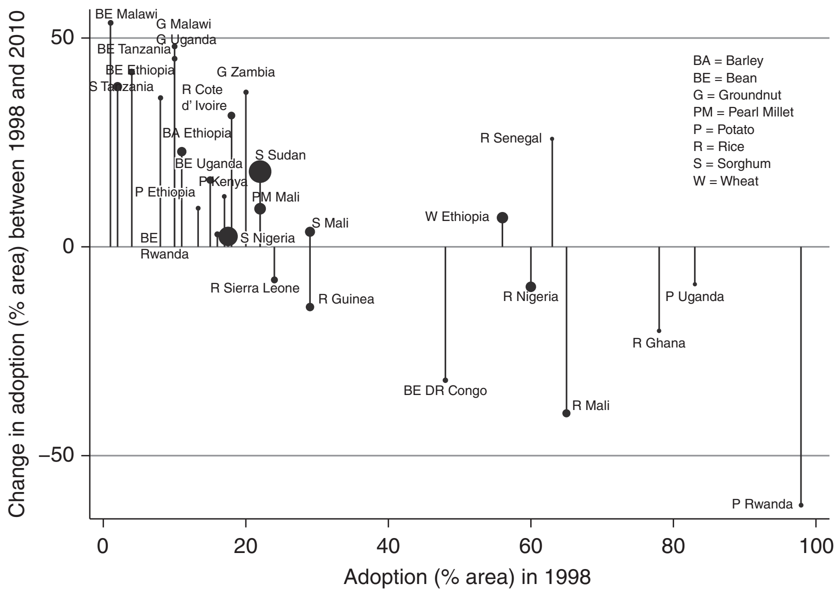

Fig. 19.2. Change in the estimated level of adoption of improved bean, groundnut, pearl millet, potato, rice, sorghum and wheat varieties between 1998 and 2010.

Unlike cassava and maize in Fig. 19.1, the relative importance of MVs declined in several countries between the 1990s and 2010. In particular, the adoption estimate for improved clones of potato decreased sharply from 97% of the harvested area in 1993 to 35% in 2010. As discussed, potato MVs became less important because of the devastation in Rwanda caused by the 1994 Genocide, which did not predate the 1998 Initiative because the adoption estimates for Rwanda referred to 1993.

In contrast, the estimated deteriorating position of MVs in rice could be attributed to a change in methods. Expert opinion panels were used to generate all the estimates for rice MVs in 1998. Surveys funded by the Japan International Cooperation Agency (JICA) were deployed by researchers in AfricaRice to arrive at nationally representative estimates of MV adoption in 20 African countries from 2008–2011.

If progress in MV adoption was slow, switching methods could be sufficient to change a small positive outcome to a meagre negative consequence.

Similar to the evidence presented in Fig. 19.1, countries characterized by moderately high levels of adoption in 1998 had a hard time maintaining these levels, let alone achieving gains in adoption. Rice in Senegal and, to a lesser extent, wheat in Ethiopia are the only two crop-by-country observations that exhibited substantial gains in adoption from 'moderate' to 'high'. Gains in adoption were concentrated at the lower end of the x axis in Fig. 19.2 in much the same manner as very positive outcomes were clustered in the same region of Fig. 19.1.

About 90% of the paired observations in Table 19.5 showed an increase in the uptake of improved varieties (Figs 19.1 and 19.2). Again, disadoption and/or overestimation of MV adoption levels in 1998 occurred mainly in potatoes and rice. The finding of a few cases of disadoption is unexpected because the ending of fertilizer subsidies is frequently mentioned as a motivation for reversion to local varieties. The evidence for disadoption is sparse in maize, which is the most intensive user of fertilizer among the food crops in the DIIVA Project.

Revisiting the hypotheses about varietal adoption

We found widespread support for several of the adoption-related hypotheses in Chapter 3. In particular:

- The level of adoption of improved varieties and hybrids was steadily increasing over time and was substantially higher in 2010 than in 1998.
- Spill-over varieties were found in all food crops and they laid claim to a sizeable share of adopted area.
- The share of materials related to CG Centers was higher in varietal adoption than in varietal output.

Findings on the above hypotheses varied by crop, but, in general, they were largely affirmative for the 20 crops as a whole. The evidence was not as generic in its support for the other two adoption-related hypotheses expressed in Chapter 3. First, disadoption of improved varieties on aggregate was rare and was not caused by economic restructuring and liberalization. We did not encounter support for the contention that increasing fertilizer prices led to the widespread abandonment of maize MVs and a reversion to traditional varieties.

Replacement of improved sorghum cultivars in Nigeria and reversion to local varieties were the most notable example of disadoption in the DIIVA database (Ndjeunga *et al.*, 2011). These varieties were extended to farmers in the late 1990s and were partially accepted by the early 2000s. Gains perceived by farmers in earliness and insect tolerance did not compensate for perceived losses in drought tolerance, stalk strength and head size to result in sustained adoption. Differences in yield and income between adopting and non-adopting households were not statistically significant. The absence of wider impacts was attributed to disadoption (Ndjeunga *et al.*, 2011). In contrast, pearl millet MVs in northern Nigeria were associated with significant differences in yield and income.[3]

Second, we documented sufficient cases to support the proposition that adoption of improved varieties was positively influenced by market demand, the potential of the production environment and the crop's multiplication ratio. The case for market demand was epitomized by haricot bean exports that stimulated greater uptake of improved varieties relative to other pulse crops in Ethiopia and relative to other bean-producing countries. Small, incremental gains in adoption between 1998 and 2010 for countries and crops with good adoption outcomes in 1998 were indicative of ceiling rates of adoption emerging in some subnational regions where production prospects were more marginal than those where diffusion had initially occurred. With a multiplication ratio of only about 15, groundnut was an apt example of crop for which high seed costs dampened diffusion of MVs, even though there is good market demand in many cases.

In spite of the general and specific favourable findings for these adoption-related hypotheses, improved varieties have diffused more slowly in SSA than in other developing countries. The average speed of diffusion was estimated at 0.11, which is considerably below the low threshold benchmark of 0.20 that comes from a survey of relevant studies (see Fuglie and Marder, Chapter 17, this volume).

Moreover, we should not lose sight of the fact that adoption of improved varieties and hybrids in dryland food crops in South Asia is markedly higher than the levels estimated in SSA (Chapters 13 and 14, this volume). Across the five rice-growing countries in Chapter 13, adoption of MVs averaged about 80% in 2010 and is still trending upwards since 1999. For pearl millet, sorghum and groundnut, levels of MV adoption ranged from about 55–70% in peninsular India. A comparable interval for the uptake of improved cultivars in these three important crops in SSA is 20–30% in 2010 (Table 19.1).

The regional estimates by state in India in Chapter 14 suggest that some important growing regions have continued to be bypassed by the Green Revolution. For all intents and purposes, post-rainy-season (rabi) sorghum production on residual moisture in peninsular India is still dominated by the old selected landrace M35-1, although the post-rainy-season crop now contributes to the bulk of sorghum output in India. Likewise, relatively few groundnut cultivars released in South India since independence have been able to compete with the old improved variety TMV-2. These examples of negligible varietal change highlight the observation that the production environment can prove to be a formidable challenge to progress even in a reasonably efficient and stable system of national and international agricultural research and in an institutionally enabling environment. Fortunately, few of these 'dry holes' are visible in the landscape of modern varietal change in South Asia in dryland food crops. And the situation is dynamic. Until recently, the prospects were believed to be bleak that pearl millet hybrids could penetrate into the arid drylands of Rajasthan. Now, more than half of the area is sown to hybrids in India's largest millet-growing state.

Varietal Turnover

The velocity of varietal turnover in 2010 by crop

The average results by crop are tightly clustered in the range of 10–20 years (Table 19.6). This means that there may be few, if any, crops where older-adopted improved materials have substantially eroded the profitability of plant breeding. But, by the same token, there was also little evidence that rapid varietal change is taking place. The area-weighted grand mean is 14 years, indicating that the average MV in farmers' fields in 2010 dated from 1996.

Only 16 of the 117 crop-by-country programmes were characterized by above average adoption combined with a varietal age of less than 10 years. These better-performing crop-by-country

Table 19.6. The velocity of varietal turnover of improved varieties in farmers' fields in SSA by crop.

Crop	Varietal age (years)	Number of country programmes
Banana	10.2	1
Sweetpotato	10.3	5
Groundnut	11.7	5
Chickpea	11.9	2
Cowpea	11.9	16
Lentil	12.5	1
Maize (WCA)	12.8	11
Wheat	12.8	1
Maize (ESA)	13.0	8
Beans	13.8	9
Cassava	14.1	17
Soybean	14.2	11
Pearl millet	14.8	3
Rice	15.8	4
Sorghum	17.4	6
Pigeonpea	17.9	2
Yam	18.4	5
Barley	18.5	2
Field pea	18.9	1
Potato	19.4	5
Faba bean	20.7	2
Weighted mean/Total	14.0	117

entries are a blend of larger-area programmes in maize, cassava and cowpea with several very small programmes in soybean and rice.

The cropwise results on varietal turnover in Table 19.6 are somewhat counterintuitive because crops such as sweetpotato and banana, with low multiplication ratios, are characterized by a younger portfolio of varieties compared with several propagated crops with stronger market demand. However, this is not surprising because of the dearth of earlier research on these clonal crops that translated into few, if any, releases in the 1980s and 1990s.

Table 19.6 contains several other surprises. For example, soybeans should have performed better on area-weighted average age given its emerging and expanding cultivation in SSA. However, the youngest soybean varieties in farmers' fields in Nigeria are 'old' because they were released in the early 1990s.

The lack of difference in varietal age between maize in WCA and ESA is also unexpected. Improved cultivars in WCA are OPVs; hybrids dominate maize production in ESA. Historically, and especially in the last decade, many more hybrids have been released in ESA than OPVs in WCA. Yet, the genetic and seed market-related differences between these two contrasting types of material have not translated into substantial differences in varietal turnover. H-614 is the dominant hybrid in Kenya. It was released in 1986. HB-660 is less dominant but it is the leading improved cultivar in Ethiopia. Both hybrids are closely related with the same parental materials. They trace their roots to the Kitale Station in Kenya from crosses between Kitale Synthetic and Ecuador 573, a landrace from the Andean Highlands collected by the Rockefeller Foundation in 1953 (De Groote, 2013, personal communication). In Kenya, the mean varietal age of hybrids and improved OPVs across the six maize-producing agroecologies was 24 years in a nationally representative adoption survey in 2010 (Swanckaert *et al*., 2012).

The vintage of adopted varieties

A small majority of the 1145 cultivars in the adopted variety database carry information on the date of release. These varieties account for about 80% of the adopted area and value of production. Their age distribution is presented in Table 19.7. The largest area and value share come from the cohort of varieties that were released in the late 1990s. This finding suggests that CG Centers were able to supply materials for release by their NARS partners during a time of financial crisis in the late 1990s and early 2000s. From this, it is possible to infer that financial constraints did not entirely stop the flow of materials in the pipeline. A 15% value share for varieties released between 2006 and 2011 is encouraging and indicates that materials in the pipeline are finding a home in farmers' fields. A sizeable chunk of the recent difference between the area and value share has been attributed to the release of two promising improved yam clones in Nigeria.

The share estimates in Table 19.7 also hint at the longer-term impact of varietal change. Improved varieties in the early 1980s are still making a substantive contribution that cannot be ignored. A case in point is IITA's release of its important cassava variety TMS 30572 in 1984. In contrast, materials released prior to 1980 in the early years of the CGIAR were relatively limited in number and their impact has eroded over time.

Comparing levels of varietal change in 1998 and 2010

Improved varieties are not getting any younger in farmers' fields. For maize and wheat, age is

Table 19.7. The vintage of varieties contributing to adoption in 2010 by criterion and by release period.

	Criterion	
Release period	Area share (%)	Value share (%)
1970–1975	1.7	1.1
1976–1980	2.7	2.9
1981–1985	8.3	10.6
1986–1990	12.7	12.8
1991–1995	19.4	15.6
1996–2000	27.1	23.9
2001–2005	17.7	17.4
2006–2011	10.3	15.2
Total area ('000 ha)	27,477.4	
Total value in US$ (million)		12,095.20

roughly the same as it was 14 years ago. For three of the four countries producing potatoes, varieties are becoming older. For rice, the average age of MVs was the highest of the cereals in both 1998 and 2010 for the same observations in both benchmark periods. Varietal age of maize in Kenya has increased slowly but surely from 17 years in 1992 to 22 years in 2001 to 24 years in 2010 (Swanckaert *et al*., 2012). Although age has fallen markedly in the dry transitional zone in response to rapid varietal adoption and change, new private sector seed suppliers have not been able to penetrate into other zones where adoption levels are stagnating.

Revisiting the hypotheses about varietal turnover

The expectation that *varietal turnover is relatively high and is increasing over time* was not supported by the estimates of age of improved varieties in the fields of African farmers. However, in contrast to outcomes on adoption, varietal turnover is not significantly faster in dryland crops or in rice in South Asia. Indeed, improved varieties in rice paddies in South Asia are older than most food-crop varieties adopted by farmers in SSA: their average age varied from 14 to 25 years across the five study countries and the three study states in India in Chapter 13 (Pandey *et al*., this volume). Very slow varietal turnover in rice has eroded the returns to recent investments in national and international rice improvement and is mainly attributed to the enduring popularity during the past three decades of Swarna, a variety characterized by widespread adaptability and stability.

Four of the five dryland crops in Chapter 14 (Kumara Charyulu *et al*., this volume) would also fall in the range of 10–20 years shown to be typical for crops in SSA in Table 19.6. Pearl millet is the exception. Indian farmers who first adopted pearl millet hybrids in the late 1960s and early 1970s are now sowing their 4th or 5th hybrid. Because of downy mildew epidemics caused by the breakdown of genetic resistance, pearl millet hybrids need to be replaced every 5–10 years. Failure to replace susceptible hybrids leads to sharp declines in yield and so-called 'boom and bust' cycles in productivity (ICRISAT, 2004). Maintenance breeding is a must and is characterized by high returns. Molecular biology has accelerated the search for sources of genetic resistance to downy mildew that, in turn, should result in a speedier turnover of popular pearl millet hybrids.

Impacts

The substantive results on estimated impacts from the DIIVA impact studies are described in detail in Chapters 15–17. The direction and order of magnitude of these results were in line with expectations at the start of the project in 2010.

Yield

Quantifying differences in productivity in replacing traditional with improved varieties received the lion's share of attention in the DIIVA impact assessment studies. Without reliable estimation of productivity differences, further measurement of impacts of varietal change on poverty, food security and other consequences would have been flawed (Chapters 15 and 16, this volume).

The estimated yield differential from adopted improved varieties over local replaced varieties varied from 0% to 100% in dryland agriculture in the case studies based on nationally or regionally representative surveys that are described in Chapter 4. At one extreme, no significant productivity differences were documented between improved and local sorghum varieties in northern Nigeria (Ndjeunga *et al*., 2011). The absence of detectable yield differences was believed to be an important determinant in the recent disadoption of these improved varieties.

Pearl millet and groundnut in northern Nigeria reflect the conventional wisdom that productivity gains from 'naked' varietal diffusion – adoption without changing input use or management practices – are likely to be statistically significant but small in rainfed agriculture in SSA. The estimated increase in pearl millet productivity was about 90 kg per adopted hectare, equivalent to a 15–20% yield gain (Ndjeunga *et al*., 2011). Likewise, improved groundnut varieties yielded about 15–20% over local varieties (Ndjeunga *et al*., 2013). This relative advantage translated into a higher productivity increase of 150–200 kg per hectare because groundnut is produced in more rainfall-assured production subregions in northern Nigeria than pearl millet.

Higher relative yield gains favouring improved varieties were recorded for beans in Rwanda and Uganda and for maize in Ethiopia. Production of these crops takes place at higher elevations and in regions of higher production potential than pearl millet and sorghum production in the hotter arid and semi-arid zones of West Africa. Improved varieties conferred a yield advantage of 53% in Rwanda and 60% in Uganda in bean production (Larochelle *et al.*, Chapter 16, this volume). In Ethiopia, maize hybrids and improved OPVs out-yielded local landraces by 48–64% in farmers' fields (Zeng *et al.*, Chapter 15, this volume). Farmers in Ethiopia spent, however, about 23–30% more in production costs in inputs such as hybrid seed, fertilizer and herbicide. Maize in Ethiopia was the only case study where adoption of improved varieties was accompanied by substantial investment in complementary inputs.

The aggregate estimate of the contribution of improved varieties to increased productivity in SSA in all food crops from 1980 to 2010 was at the higher end of the spectrum defined in the case studies. The impact of improved varieties on farm productivity in SSA has been significant, raising average net crop yield on adopting areas by around 0.55 tonnes per hectare, or by 47%, from 1976–1980 average levels (Fuglie and Marder, Chapter 17, this volume).

Poverty

Persuasive evidence on the poverty consequences of improved varietal change was presented in the case studies on maize in Ethiopia and on beans in Rwanda and Uganda (Chapters 15 and 16, this volume). The impact on poverty was small in bean production. Annual profits from bean growing (accounting for two growing seasons in each country) increased by about US$75 and US$65 per bean-growing household in Rwanda and Uganda, respectively, compared to what they would have been in the absence of the improved varieties. Without improved varieties, poverty would have been about 0.4% higher in Rwanda and 0.1% higher in Uganda in 2011. A modest poverty impact was attributed to the small area planted to beans – in both countries and cropping seasons the median-sized sown area was only equivalent to about one-sixth of a hectare – and the relatively small contribution of bean consumption and sales in total household income. In Uganda, the poor have not adopted improved bean varieties as widely as households above the poverty line.

The adoption of maize hybrids and improved OPVs in Ethiopia generated large poverty impacts. At 0.85 hectares, the average maize-growing area in Ethiopia was more than five times larger than the mean bean area in Rwanda and Uganda; maize figured more prominently in household income. Lower food prices on poor net consuming households were as or more important than direct income gains to producers in reducing poverty in Ethiopia. Diffusion of improved maize cultivars led to a 0.8–1.3% reduction in the overall rural poverty headcount ratio, and to proportional declines in the depth and severity of poverty. Between 45,000 and 95,000 rural households were no longer classified as poor in 2020 because of the adoption of improved maize genotypes.

As the total cropping area under maize is still expanding in Ethiopia, the poverty impacts of improved maize varieties should continue to increase in the future. Unlike in the case of bean producers in Uganda, the poor were found to be as likely to adopt improved varieties of maize as the non-poor, holding all other factors constant, and they experienced similar yield increments and reductions in the cost per unit of production from adoption. The small size of their land holdings, rather than their inability to adopt, explains why they derived fewer absolute benefits from adoption.

The magnitude of the monetary measure of US$6 billion/year also bears witness to the potential for poverty reduction from improved varietal change. If present adoption rates and per hectare impacts continue, the added value from improved varieties could approach US$12 billion/year by 2020 (Fuglie and Marder, Chapter 17, this volume).

Food security

Bean in Rwanda and Uganda was the only case study to address the impact of improved varietal change on food security (Larochelle *et al*., Chapter 16, this volume). In Rwanda, 16% more households would have been food insecure without improved bean varieties; in Uganda, 2% more households would have been food insecure. Initially, households in Uganda were characterized by greater dietary diversity and this partially explains why the effect of improved bean varieties in Rwanda on food security was substantially larger than in Uganda.

Revisiting the hypotheses on impacts

As pointed out in Chapter 3, the hypotheses on impacts were not as well formulated as those for other aspects of the DIIVA study. Nonetheless, much of the thinking by authors of the DIIVA proposal and of the impact assessments about the effects of improved varietal change was confirmed by the case studies and by the aggregate analysis in Chapter 17. The net yield gains in the case studies spanned a wide range from 0% to 100%. The quality of the production environment loomed large in conditioning favourable yield gains and in the use of additional complementary inputs that reinforced productivity differences. Large poverty effects for improved maize varieties in Ethiopia and notable food security consequences were documented for improved bean varieties in Rwanda. As expected, the aggregate time-series analysis in Chapter 17 showed that varietal change was an important contributing factor to technological change in food-crop agriculture in SSA.

Although we did not scour the landscape, we did not encounter any evidence for negative unintended consequences. The transfer of improved sorghum cultivars in northern Nigeria could be called the worst-case scenario we encountered. That expenditure on extension now seems to have been wasted because widespread disadoption is reported (Ndjeunga *et al*., 2011). The strengths of these newer varieties do not appear to compensate for their perceived weaknesses. In contrast, sustained adoption of improved pearl millet and groundnut varieties has taken place in northern Nigeria (Ndjeunga *et al*., 2011; Ndjeunga *et al*., 2013).

Notes

[1] Every effort was made to minimize the number of varieties in the ‘other’ category. Most of the specific entries come from survey data and refer to names that are believed to be MVs but that could not be linked to a specific released variety. A few of the observations based on expert opinion also have a small residual ‘other’ category.

[2] Value of production is an important criterion because varietal change in crops with more attractive prices and/or higher base yields has the potential to generate greater net benefits per hectare of adopted area.

[3] When SOSAT-C88 was first introduced, its seed sold for six times the market price of pearl millet in northern Nigeria (ICRISAT, 2000). SOSAT C-88 is prized for its early maturity, insect tolerance, grain colour and its quick cooking time (Ndjeunga *et al*., 2011). Low fodder production and susceptibility to *Striga* are its main weaknesses.

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