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Making seed systems more resilient to stress

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ABSTRACT

While seed security is key to food security, concrete means for building resilient seed systems remain unexplored in research and practice. A new toolkit, the Seed System Security Assessment (SSSA), examines what actually happens to seed systems during crises and highlights specific features that foster or undermine resilience. Drawing evidence from SSSAs in contexts of political and civil conflict (Zimbabwe and South Sudan), earthquake (Haiti) and drought (Kenya), the article shows that seed systems prove to be relatively resilient, at least in terms of meeting farmers' planting needs for the upcoming season. Altering crop profiles, making use of multiple delivery channels, and innovating (for example, with new barter mechanisms) all become key, as does mobilizing cross-scale seed supply linkages. However, despite short-term survival, in the medium term, both formal and informal seed systems will have to be transformed to address agro-ecological and farming system challenges, partially shaped by global environmental changes. Key is that formal seed systems will play a catalytic but supporting role, with the onus on resilience response lying within informal systems, and especially with local markets and their traders. Also key is that achieving seed security in fluctuating environments will hinge on developing resilience-linked information systems which put as much weight on helping farmers strategize as on delivering the planting material itself. The article defines seed system resilience, identifies eight principles linked to processes that build such resilience, and makes 15 practical recommendations for enhancing seed system resilience in the short and medium term. Finally, drawing insights from seed systems, processes central for building resilience in other development sectors are highlighted.

1. Introduction

Agricultural crises receive significant levels of aid through both emergency and more development-oriented responses, for example, $3.9 billion in aid for 2006 alone (Curtis, 2008). Such interventions tend to respond to immediate acute crises (e.g. food shortages), typically through providing inputs such as seed and fertilizer. However, emphasis solely on acute response is often short-sighted. Behind many acute problems are more chronic stresses, such as declining soil productivity or weak institutions. Moreover, responding to perceived acute crises, again and again, is expensive and growing evidence suggests that a more cost-effective strategy aims to build a system's capacity in advance to absorb stresses and adapt to changes – in other words, to build its *resilience* to stress (Davies et al., 2008; World Bank and United Nations, 2010). Given the challenges facing agriculture, not least those resulting from global environmental change, building resilience is a priority (Foresight, 2011; Thornton et al., 2011). Seed systems are an important area for enhancing such resilience as seed security has several direct links to food security (McGuire and Sperling, 2011) and to resilient livelihoods more generally (e.g. access to the right seeds can facilitate response to changing conditions). However, building resilient seed systems remains relatively unexplored in research and practice.

Seed-related interventions tend to be the major agricultural-linked response following crises and typically take the form of supplying seed directly to beneficiaries. Such interventions rarely diagnose constraints in advance, so are not tailored to actual stresses in a seed system and likely make little contribution to resilience (Sperling et al., 2008). In fact, poorly designed seed aid can actually undermine resilience by: providing mal-adapted or untested new varieties; narrowing the diversity of crops/varieties in key supply channels; 'crowding out' local seed enterprises; or weakening farmers' adaptive behaviors through dependency on repeated aid (Sperling and McGuire, 2010a). Such detrimental effects of aid are avoidable and, crucially, building resilience can start immediately after the emergency response phase, taking into

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account both acute and chronic stresses. Existing literature on key components for resilient seed systems is limited, focusing mainly on supply channels in formal or farmer systems (e.g. Bellon et al., 2011; Challinor et al., 2007). A more systemic perspective is needed, particularly one that recognizes dynamic responses to change across seed systems, involving trade-offs among goals, crops, channels and other key features (Sperling and McGuire, 2010b).

This article addresses this important gap in seed system analysis and intervention, helping to improve understanding of seed system factors that build, or undermine, resilience to stress. The next section introduces a tool which helps uncover the dynamics of how seed systems function in normal and stress periods, the Seed System Security Assessment (SSSA). A brief review of the literature on resilience follows, outlining key principles and a definition tied to seed systems. SSSA-linked case studies from Haiti, Zimbabwe, South Sudan and Kenya then highlight the aspects of seed systems that affect resilience in practice, drawing from diverse stress contexts. Finally, the article focuses on strategic programming actions: how to foster resilience in seed systems in the short and medium-term. Many of the research and development features recommended are also central for building resilience in other sectors of development.

2. Seed System Security Assessment (SSSA): from shaping aid to analyzing seed systems

Seed interventions can be implemented just after acute crises, starting in the recovery and moving into the rehabilitation and developmental phases. They are widespread: for example, the FAO alone supported 400 emergency seed projects between 2003 and 2005, spent US$ 358 million on emergency operations in 2007, and had seed project plans for 48 countries for 2008 during the food price crisis (FAO, 2005; UN News Centre, 2008; T. Osborn, Pers. Comm. January 2009). This ubiquity of intervention reflects seed's importance but also widespread perceptions that this form of aid empowers farmers, helping them 'get back on their feet' to produce their own food quickly. However, in practice, specific seed security needs are rarely identified prior to action, intervention goals are unspecified, and post hoc evaluations are lacking – all of which raise questions about whether the aid being put forward is the right type. Intervention programming usually focuses on immediate 'known' responses, such as Direct Seed Distribution (DSD) or vouchers and seed fairs, reflecting institutional preferences rather than responding to actual problems encountered (McGuire and Sperling, 2008).

The SSSA toolkit is a response to this proliferation of supply-driven seed-based interventions. The SSSA was developed for rapid field assessment in highly stressed regions receiving (or about to receive) aid, and has been applied to a number of countries and regions (e.g. South Sudan, Eastern Kenya, Haiti, Zimbabwe, Southern Malawi, Eastern Congo, Ethiopia, northern Mali).

SSSAs focus on the functioning of the varied channels farmers use to obtain seed for their key crops, which include retained harvests, local exchange, informal seed/grain markets, as well as government and commercial outlets, and aid interventions. Seed security is the core analytical framing, with assessed aspects of seed security including: *availability* (is there seed in reasonable proximity?); *access* (are farmers able to obtain it through purchase, exchange or social access?) and *quality* (are the genetic and phytosanitary qualities valued? Do traits on offer meet farmer and market preferences?). Methods look at both the demand and supply-side and include a range of qualitative and quantitative methods so as to provide a systems perspective, analyzing: formal and local market functioning, policies, agricultural research efforts, aid projects, relationships between actors, and major drivers of livelihood change. Analyses also explicitly are socially disaggregated and span temporal and spatial scales – e.g. considering long-distance seed trade, or seed use trends over time. Methods are detailed further in Sperling (2008).

SSSAs are both practice- and policy-oriented, developing a range of recommendations and engaging with actors to promote their implementation. Their value is not only for emergency seed aid practice, however, as they also offer insights into the dynamism of seed systems including more chronic stress issues as well as developmental opportunities. Considering the system as a whole, SSSA findings highlight aspects of resilience perhaps not previously appreciated by government or non-governmental officials. The next section draws from the general literature on resilience, to outline key principles for resilience in seed systems.

3. Resilience and seed systems

Seed systems are just starting to receive mention in relation to resilience per se. Much of this initial discussion of seed system resilience is framed around promoting more integrated systems, linking formal and informal seed sectors, which presumably will give a degree of stability along with production gains (Bellon et al., 2011; Burke et al., 2009; Louwaars and de Boef, 2012). The "static and bureaucratic" nature of formal seed systems (Lybbert and Sumner, 2012, p. 120) has often been noted as a barrier to such integration. However, further specific elements of seed system resilience have not yet been elaborated.

The literature on resilience is theoretically rich, but with as yet few examples of application to management activities or policies in Southern farming systems (Béné et al., 2011). However, the socio-ecological systems literature offers particular insights, which helps frame key principles for resilience in seed systems. We outline eight of these below.

A core concept in the literature is that resilience is not solely determined by asset levels or individual household characteristics, but rather emerges as a property of socio-ecological systems, influenced by the interplay of bio-physical features and institutions (Young, 2010), cross-scale linkages (Anderies and Janssen, 2011; Robinson and Berkes, 2011) and social memory (Folke, 2006), among other features. For seed security, (1) this underscores the priority importance of a *systems* perspective, and not a narrow focus on just the material, seed, but rather with attention to institutions, relationships, and knowledge, spanning processes in both formal and informal systems. Another key resilience concept is that it extends beyond simple persistence or robustness, to refer to systems' capacity to absorb shocks and undergo change, while still retaining key aspects of structure, function, and identity (Walker et al., 2006). For seed systems, this means that (2) maintaining a particular system state (such as a crop profile) should not be the goal, but rather *retaining seed system function*, with maintaining farming livelihoods and alleviating poverty being priority functions.

The unpredictability of change, due to inter-connections linking geographical and temporal scales (Adger et al., 2009), also emerges as key in the broad resilience discourse. This unpredictability works against single optimal solutions (Béné et al., 2011). Consequently, (3) *diversity* is important for seed system resilience, in terms of crop, of variety and even of supply channels. Not all diversity is equally functional and rotating germplasm and outlets to deal with unpredictable time (seasonal, yearly) and geographic variation becomes essential. Also, (4) *temporal breadth* needs to be integral. Seed security means having the right seed available and accessible not just for the imminent planting season, but also for several seasons thereafter. Hence, though *planning for the very short-term*, even the next three months is important, shaping resilient seed systems *also requires longer-term strategy*. Innovation and learning are also central for responding to dynamic change – and the resilience literature cautions that an over-emphasis on outcomes (such as delivering seed) can hamper understanding of learning as a process (Tschakert and Dietrich, 2010). Applied to seed systems, this means that (5) technology provision should be linked to *relevant information to assist strategic decision-making*. Abundant short-term and long-term information e.g. seasonal dynamics, variety performance, and effective market links will be important here (Lybbert and Sumner, 2012; McGuire and Sperling, 2011). Another resilience principle related to learning is that (6) *feedback loops* have to be fostered among different parts of systems, for instance, between farmer–clients and suppliers, or between traders and formal institutions. Select literature highlights the importance of managing change in a way that strikes a balance between sustaining and transforming systems (Folke, 2006). For seed systems, this suggests (7) *a repertoire of flexible responses*, which help smallholder farmers to maintain current seed security features (availability, access, utilization), but which also enable them to transform and evolve as new positive possibilities present themselves, for instance agro-enterprises which could drive demand for seed. Finally, the resilience literature cautions that trade-offs are a risk in managing for resilience. Response strategies for one type of stress can be maladaptive if they lower resilience to other stresses (Anderies et al., 2006), decrease flexibility (Fazey et al., 2011), or bring with them new types of risk (Silva et al., 2010). This leads to our last seed system resilience principle, (8) interventions must consider *trade-offs* between multiple stresses and risks, for instance, introducing cash-crops for income-generation prior to the development of real market demand. As many smallholder farmer populations are already at the margin, increasing their vulnerability even in the short term can be detrimental over longer time horizons.

Embracing these eight principles, we define seed system resilience as follows. Resilient seed systems have the capacity to absorb shocks and stress, and reorganize so as to maintain and strengthen seed security over time. Resilience emerges as a property of germplasm, institutions, and interactive information systems, which allow for strategic response to change.

4. SSSA cases

SSSAs offer important insights into resilience, with their focus on the diversity of crops and supply channels, challenges of seed access, and the dynamic strategies used to maintain seed security. With their attention to multiple actors, scales, and processes, SSSAs also offer a rapid understanding of seed systems under stress.

In this section, we briefly present four SSSA case studies. These cases feature different acute shocks, political and civil conflict, drought and earthquakes, but all face chronic stresses as well, particularly around environmental conditions, poverty, and institutional support. Thus defining these cases solely in terms of acute stress is simplistic and offers but a truncated analysis. Table 1 provides a quick overview of the case studies chosen.

4.1. Zimbabwe

Emergency seed aid has been routine in Zimbabwe (occurring in 15 of the last 29 years), in response to frequent droughts, input bottlenecks and currency breakdown. For 2009–2010, donors sought US$140 million, planning to supply seed (mainly hybrid maize) and fertilizer to 600 000 families, half the farming population, the largest distribution of recent years. The Zimbabwe SSSA (CIAT et al., 2009) took place in mid-2009, while such aid was being planned. Zimbabwe's formal (commercial) seed sector is unusually developed, with more than 15 companies supplying seed, primarily for maize. However, formal seed production in Zimbabwe virtually collapsed between 2006/2007 and 2009, along with allied rural businesses such as agro-dealers, as hyper-inflation (reaching 56 million % in 2008; FAO/WFP, 2009) and policies such as price controls posed severe challenges to seed businesses. Only in 2009 did inflation come under control following liberalization of input and output markets and a switch to use of the US dollar.

The SSSA highlighted an apparent conundrum: despite following two drought-affected years with low crop production, the 2008–2009 season was a success, producing above long-term averages, and 130% above the previous season. Also, contrary to assumptions in the aid community, farmers were generally seed secure. For crops other than maize, the informal system supplied nearly all the seed farmers sowed. Farmers' own harvests and social networks provided 40–92% of total seed for key crops in 2008–2009, and 56% of seed across all crops (Table 2). Significantly, farmers also sourced from local shops still operating, developing complex barter economies to meet input needs in the face of hyper-inflation. Vigorous unregulated markets also supplied hybrid maize, often broken up into smaller packet sizes to increase accessibility. Diverse barter exchange rates reflected local scarcities (e.g. for groundnut in Beitbridge; see Box 1). New varieties entered local systems for different crops, through diverse means such as on-farm trials, cross-border trade, or seed fairs, which helped keep local seed systems dynamic. Finally, the SSSA showed that formal (commercial) seed production and marketing was recovering after the 2009 liberalization, with producers and agro-input dealers re-opening, though at modest scales and still vulnerable to being undermined by DSD in seed aid.

This SSSA showed how feedback loops between formal and informal systems helped maintain a diversity of crop varieties, suppliers and seed production mechanisms, helping many farmers access seed. The default seed security response, DSD, would actually undermine commercial enterprises and thus stifle these links. Though US$150 million was spent on such in-kind aid in 2008–2009, the SSSA helped spur a move to market-led aid

Table 1
Overview of SSSA studies presented.

SSSA country	Date	Stress context		Key crops	Methods: number of		
		Immediate (acute)	Longer-term (chronic)		Study sites	Interviews/ discussions[a]	Farmer surveys
Zimbabwe	2009	Political instability/ currency collapse	Declining purchasing power	Maize, groundnut, sorghum	4	48	165
Haiti	2010	Earthquake	Absence of state, low innovation	Beans, maize, pigeonpea	11	60+	983
S Sudan	2010	Post-conflict	Absence of state, weak infrastructure	Sorghum, maize, groundnut	16	95	885
Kenya	2011	Drought	Decline of maize, low purchasing power	Maize, greengram, cowpea	3	58	199

[a] Individual focus group discussions and market trader interviews; the many additional meetings with experts and projects in each SSSA are not included here.

Table 2
The relative importance of different seed sources for supplying farmers with the seed they planted in the first post-crisis season.

SSSA country	Season	*N* observations[a]	Sources of seed used (%)						
			Own stocks	Friends, neighbors, kin	Local markets	Agro-dealer	NGO	Gov't/other	Total
Zimbabwe	2009	533	40.3	16.0	17.2	7.3	10.4	8.9	100
Haiti	2010	3583	17.8	1.9	74.2	1.5	4.1	0.5	100
South Sudan	2010	3571	42.1	26.0	22.2	0.1	8.6	1.0	100
Kenya	2011	625	37.9	4.4	38.5	13.4	0.6	5.2	100

[a] As farmers could detail seed received from multiple sources for each of three priority crops, observations are greater than number of farmers interviewed.

responses by 2010 (including vouchers, input fairs, and support to local enterprises), which aimed to increase farmers' purchasing power and inject cash into local economies. Promoting farmers' ability to access seed of their choice, and fostering diversity of varieties and access channels, are important to support resilience in this context.

4.2. Haiti

Haiti has significant food-insecurity – 57% are under-nourished (FAO, 2010) – and is vulnerable to regular shocks such as hurricanes. The January 2010 earthquake near the capital caused heavy casualties, urban-to-rural migration (perhaps 500 000 initially left affected areas), and disrupted economic activity and services. Fears that the earthquake would exacerbate vulnerability prompted large-scale emergency appeals, including US$70 million for seeds and tools for roughly a third of the rural population (Haiti Grassroots Watch, 2011). The SSSA (CIAT et al., 2010) took place May/June, in the middle of the first post-earthquake season.

Aid agencies initially circulated reports of 'farmers eating seed' as a sign of unusual distress, which required aid. However, the SSSA showed that Haitian farmers routinely eat or sell nearly all of their harvests for crops such as beans as markets are easily able to re-supply needed stocks. In fact, Haitians normally obtain 74% of their seed from local markets across diverse crops (the highest rate recorded in a seed assessment anywhere; Table 2).

Post-earthquake, seed remained available through these markets. Sowing amounts nationally were 15.9% below normal that first season, though this was mainly due to financial constraints on access, land tenure changes and delayed planting due to drought – rather than seed unavailability. Farmers planned to sow 15.3% more seed than normal for the second post-earthquake season, suggesting few acute seed security issues, apart from weakened purchasing power. Women are centrally involved in agricultural trade, and many women supplement farming with petty commerce (inter alia, trading in grains or processed foods such as banana fritters or beer). Sharp drops in rural trade and disrupted market-chain relationships meant many women lost income, which indirectly affected seed security.

Chronic stresses, however, were striking. Haitian farming faces clear 'double exposure' (Silva et al., 2010) to global market trends, as well as to environmental hazards, due to low import tariffs (Cohen and Garrett, 2009). The near-absence of agricultural research severely constrained access to innovations: in fact, only 14% of farmers encountered any new crop variety in the past five years, the lowest rate found in any of the SSSAs (Table 3). Further, in Haiti, nearly all such novelty was delivered through 'emergency' seed aid, 83% of the time. Channels are also static, with few new seed sources emerging, and scant options for adding value to harvests. The SSSA showed that donor interventions implemented here could expose farmers to new risks, where local seed production groups are developed which depend upon continued aid (i.e. artificial markets), or where new seed shops sell hybrids which are insufficiently tested in Haiti. Also, farmers' recurrent use of local markets for seed amounts to a considerable household expense, on average $US 60–70 per season.

Responses that promote resilience should target assessed seed security needs, rather than assume needs and continue to provide seed through DSD and vouchers. Innovation systems are another priority, to provide farmers with new crop/variety options, and information-rich conduits to help farmers strategize. This would involve linking seed channels to research and development, involving farmers and traders in assessing innovations, and developing value-addition opportunities (for example, mango beverages). Traders, including the well-known *Madames Saras* – women traders who move produce between regions – also present an opportunity for dynamism, if they can be provided with useful varieties and advice to pass on to farmer clients.

4.3. South Sudan (formerly southern Sudan)

The long civil war in South Sudan displaced populations, dissipated productive assets, and left large expanses of field overgrown with heavy brush and menaced by wildlife. Until the 2005 Comprehensive Peace Agreement, there was little state research or support to agriculture for this region, and development of state services has been gradual. South Sudan had regularly

Box 1. Zimbabwe 2009: local barter terms for seed, draught power and fertilizer.

Terms of trade	Where
1 goat = 10 kg hybrid maize seed	Murehwa
1 cup maize seed = 1 cup shelled groundnut seed	Tshololotsho, Murehwa Bikita
1 chicken = 5 l maize seed	Tsholotsho
10 kg top dressing or basal fertilizer = 10 kg maize seed	Murehwa
1 kg bar carbolic soap = 5 l unshelled groundnuts	Tsholotsho
20 l storage container = 20 l unshelled groundnuts	Tsholotsho
Planting labor for 2 cups of seed = receipt 1 cup of seed	Bikita
Herding labor, summer = use of draught animal tillage for 2 acres	Murehwa
Tilling 1 acre using draught animals = 1 bucket of unshelled groundnuts	Bikita
1/2 drain (about .3 ha) tillage with hoe = 1 cup maize or groundnut seed	Bikita
6½ buckets (app. 125 kg) maize grain = 50 kg fertilizer	Bikita
1 cup shelled g/nuts = 1 cup shelled Bambara nuts	Beitbridge
10 l pearl millet = 5 l groundnuts	Beitbridge
1 chicken = 5 l unshelled g/nuts	Beitbridge
1 goat = 50 kg unshelled g/nuts	Beitbridge

The terms of exchange appear to be influenced by scarcity of seed. For example in Beitbridge where groundnut seed was reported to be in short supply locally, farmers exchange a goat (very valuable) for a 50 kg bag of unshelled groundnuts.

Table 3
Farmers obtaining a new variety in 'last five years'.

Site	Date of assessment	Received new varieties (%)				New variety sources (%)			
		N farmers[a]	Yes	No	Total	*N* varieties	Seed aid	All other sources	Total
Zimbabwe	July 2009	165	70.8	29.2	100	262	45.8	54.2	100
Haiti	June 2010	983	14.0	86.0	100	249	83.1	16.9	100
South Sudan	November 2010	877	51.1	48.9	100	868	69.8	30.2	100
Kenya	September 2011	195	70.8	29.2	100	225	53.8	46.2	100

[a] A few non-responses mean N is slightly less than in Table 1.

received seed aid since 2005, with half the farming population receiving aid an average of 1.8 times (and some as many as 12!). In 2010, an SSSA examined seed security across the country in the run-up to independence (CIAT et al., 2011b). The SSSA followed a favorable season, though the one prior had been poor. Despite little government support, farmers were expanding areas sown and seed use across South Sudan (Table 4) and had obtained nearly all the seed they needed through their own channels, with harvests providing 42% of seed sowed in 2010, local markets 22% and neighbors 26% (Table 2). Diversity was vibrant, with farmers cultivating a wide range of crops (some 29 deemed priority) and varieties. Local markets provided farmers with good-quality seed, and channeled some new varieties to farmers, but extremely weak infrastructure and paucity of paved roads (only 50 km country-wide) meant links to output markets were patchy at best, constraining farmers' income-generation opportunities. Farmers obtained the majority (circa 70%) of new varieties via emergency interventions (Table 3).

For the near future, farming livelihoods proved highly dynamic, with farmers projecting leaps in seed use of 79.5% (Table 4). Note there was variability: 41% of households were planning to expand production particularly to pursue income-linked opportunities, though a third were scaling back, citing mainly labor, health and money constraints. Gender remained a central concern, with nearly half the 885 households sampled female-headed. Women's farms were smaller, and significantly fewer planned to expand areas ($p < 0.001$ for both). Women lacked access especially to the heavy labor needed to clear bushed and overgrown land and to build the fencing needed to keep monkeys, hyena (and other predators) out. This labor constraint was a more immediate issue than seed-related concerns.

Again, current supply-side DSD responses have a questionable impact on resilience. Rather, support to improving women's access to farm labor should be a priority, through supporting existing or novel associations, developing income-generating activities, and extending institutional support to rural women. Market development is also a priority, to channel new diversity to farmers, and enhance market opportunities for farm produce, decentralized seed production and processed agricultural products.

Table 4
Quantities of seed sowed for two seasons – during/immediately after shock, and the season thereafter – compared with quantities 'normally sowed'; mean % change across all crops.

Site	Change in quantities from 'normal amount' sowed (%)	
	During/immediately after shock	First season toward recovery
Zimbabwe	n/a	n/a
Haiti	−15.9	+15.3
South Sudan	+17.0	+79.5
Kenya[a]	−5.8	−0.2

n/a, data not available.
[a] Kenya data includes an important group of very vulnerable internally displaced people (IDPs).

4.4. Kenya (East and Coast Provinces)

The Long Rains (LR; March–June) failed in 2011 in Eastern and Coastal Kenya, with drought persisting to the Short Rains (SR; October–January), prompting concerns around seed security and seed aid plans. The Kenya SSSA took place to assess these drought-affected seed systems (CIAT et al., 2011a), and reflect on the impact of regular seed aid to the region over the past 20 years (Sperling et al., 2008).

Across study sites and crops, communities assessed themselves broadly seed secure, including a vulnerable internally displaced person (IDP) population. As seen in other SSSAs, farmers compensated for reduced on-farm seed stocks by sourcing more from other channels, particularly local markets (from 39 to 55% of seed LR to SR) and agro-dealers (13–27% LR to SR). Aid seed played a minimal role, though most farmers were repeat recipients. Because of inter-regional and international trade (seed even moving 150 km), local markets maintained seed availability, though there was evidence that some traders hoarded greengram, a key cash crop, to obtain better prices at sowing time. Agro-dealers supplied certified seed for maize – and limited legumes – but financial accessibility was an issue due to high unit prices combined with large packet sizes, as was physical accessibility for more remote locations. Increased use of local markets and agro-dealers strained some households due to cost – US$ 45 was calculated as average expenditure in one site for SR, roughly the cost of a goat.

Longer-term trends showed both dynamism and bottlenecks. Over 70% of farmers had accessed a new variety in the past five years, mostly for maize, greengram and cowpeas. While farmers sought maize from an increasing range of channels, few outlets supplied legume seed – many of which were subsidized and economically unsustainable – and farmers found it harder to access desired varieties. In one site (Tharaka), farmers were reverting to dryland crops like sorghum, which offer more stable, albeit usually lower, production. Finally, there was little agricultural transformation to add value to produce.

As in the other cases, responses aimed at enhancing resilience would seek to expand the availability of new varieties, particularly for legumes and forage crops, using a range of partners for seed production, marketing and awareness-raising. These need to be decentralized and accessible to small farmers. Alongside seed responses, better value-addition opportunities and market information is also needed, along with infrastructural improvements.

4.5. Summary – factors affecting seed system resilience post-disaster

Overall, these assessments challenged conceptions about seed systems that remain widely held by humanitarian actors. Even immediately after a crisis, farmers' own stocks and local markets supply the majority of seed (57–92% across sites), with gifts via social networks also important in some settings (Table 2). In contrast, agro-dealers and government projects provide only modest amounts of seed, and mostly of maize. The assessments show that: (i) seed systems display much resilience to disasters (informal seed channels often continue to function), (ii) DSD may not address priority needs (seed is usually available, though access can be a problem), and (iii) poor aid can have negative impacts (especially undermining key markets).

The cases also highlight key features affecting the resilience of seed systems. Emergency response strategies can weaken resilience if (1) by seeking 'optimal' solutions they become maladaptive, or (2) increase exposure to a new type of risk. For instance the promotion of maize in Zimbabwe hindered flexibility by neglecting other crops, and the supply of untested varieties to farmers in Haiti or South Sudan exposed them to production uncertainty. Resilience can also be undermined by (3) aid that is repeated season after season, but which misses priority constraints. This was noted in all case countries, and arose from a lack of prior needs assessments or post hoc impact evaluations, though the SSSA in Zimbabwe showed how effective evaluations can change aid practice. Resilience can also be strengthened by (4) better links between formal and informal seed systems; Zimbabwe's barter systems helped secure access to formal sector seed. Also, (5) engaging with key 'knowledge-brokers' (Walker et al., 2006) such as traders can help bridge systems, as well as cross scales – for instance, in Haiti the *Madames Sara* traders emerge as key potential partners. Moreover, (6) maximizing farmers' ability to choose helps maintain a diversity of crops and supply channels important for responding to unpredictable change; seed fairs linked to vouchers in Kenya offer good examples here. Finally, (7) links across geographical scales enhance seed security, as seen by trans-regional seed flows in Kenya, Zimbabwe and South Sudan, which ensured seed availability in local markets. This reminds us that assessments need to extend beyond local scales. Note that all these resilience features found in practice reflect the general resilience principles introduced in Section 3.

5. Achieving resilient seed systems – key areas for action

The SSSA cases suggest elements of resilience within seed systems. Zimbabwe highlights how a system with a range of market actors and functioning communication links between farmers and sellers enabled some supply channels (including elaborate barter systems) to continue to serve farmers, even during the currency crisis. In contrast, the Haiti case suggests how stagnant rural areas and limited access to innovation constrain seed system resilience, particularly when a system is as exposed to external markets as Haiti's is. Additionally, SSSA findings in these countries, and others, indicate that that it is possible to build resilience in seed systems.

We highlight below five overarching thrusts that can help enhance seed system resilience. These include short-term actions that could begin immediately after an acute shock, as well as more medium-term actions. A modest start at elaborating actions associated with each is sketched in sections following.

(i) *identifying germplasm* suited to different scenarios, which can be re-vitalized quickly: 'crop/seed systems in reserve';
(ii) *enhancing availability* of this germplasm: broadening initial formal and informal seed supplies and multiplication possibilities;
(iii) *securing access* to diverse seed particularly through the use of multiple channels (including through local markets); and planning especially to encourage access by more vulnerable groups;
(iv) *fostering information systems* that strengthen capacity for tailored response at varied levels (including at farmers') and which promote *continued learning*;
(v) *enabling evolution of systems to capture new repertoires and opportunities*. Linking seed systems to dynamic elements, particularly those opening up commercial opportunities (new markets, transformation) or those which might cross geographic boundaries.

Together, the above areas are about building up and rendering accessible reserves of knowledge and action possibilities. In some cases, this strategy implies mostly revitalizing existing repertoires. In others, creating new repertoires is central to the agenda.

5.1. What to do to enhance resilience – some programmatic recommendations

(i) *Identifying germplasm strategies in reserve* – which can be revitalized quickly.

A conventional, 'supply-driven' perspective on seed systems would propose building up of physical stocks of seed as a way to build resilience in the short-term (e.g. RRC, 1995). This perspective fits well with a modernization agenda that emphasizes a few staple food crops and varieties in crop development linked to formal multiplication, promotion, and delivery efforts. However, a resilience perspective implies that one size does not fit all. Significant agro-ecological and social variation works against a single crop or variety suiting all types of farmers or all farming conditions. In high stress areas, where variability tends to be greater, need for flexibility and options is even more pressing (e.g. Soleri et al., 2002). Added to spatial and socio-economic diversity is temporal diversity, heightening the levels of uncertainty. In such circumstances, farmers need to have a range of crop repertoires, suited to the different possible conditions that might occur. For instance, farmers in the Ethiopia's Central Rift Valley have 20 different crop combinations depending the pattern of rainfall that occurs (Fujisaka, 1997). Putting this temporal element of uncertainty at the center, as Richards (1993) observed, shifts our understanding of farming from being a plan, set out prior to the season's start, to that of a performance, done in interaction with ecological and social contingencies.

Farmers' practices in response to high variability mean that many locations already have a history of tried-and-tested crop and variety repertoires as a response to different conditions. For instance, the Kenya SSSA found farmers moving from long-season to short-season pigeonpea varieties, or reverting to growing cassava (away from maize) in response to temporal water stress and labor shortages. So in the short-term, diversity and choice have to be the operative words, and response approaches that give leeway for farmers to strategize should be favored.

This perspective is a dramatic departure from focusing on a narrow range of crop and varieties. Rather, the goal is to develop a set of *seed system strategies that are in reserve*, and which can be revitalized when needed. This means that diversity needs to be 'smart diversity' which is potentially targeted for different scenarios. Preparing for this will involve a series of medium-term actions. New germplasm has to be better characterized to understand where it grows, as well as the limits of its adaptation. In this sense geographic information systems and networks of trial sites might be useful (such as the Africa trial sites, http://www.cgiar-csi.org/center_showcase/africa-trial-sites-catalogue) to identify analogous environments and potential sources of seed. Researchers and development staff might also work with farmers to better characterize existing germplasm and use strategies: assembling (or recovering) an inventory of seed types and response strategies, for specific conditions (e.g. Tschakert, 2007). Some such information may already exist in studies of local knowledge, though often as decontextualized lists of crops and practices. Such lists only become useful repertoires when associated with information on range of adaptation at limits of stress (e.g. to which conditions are they suited, variability of response). Two issues are important to emphasize: adaptation is not just about agronomic suitability but also has to include insights on farmer preferences and market acceptability (Sperling et al., 2001); and physical germplasm (i.e. seed) is only as useful as the associated information guiding its use.

(ii) *Ensuring availability* of this germplasm and seed, broadening both formal and informal multiplication possibilities.

A consistent finding from SSSAs is that farmers use multiple sources for seed, primarily informal sources such as social networks and local grain/seed markets. Formal enterprises for certified seed provide less than 10% of seed sown for most crops in stress situations, and none at all for 'orphan' crops not reached by research. While important as links to the outputs of research (e.g. drought-tolerant varieties), formal enterprises are constrained by narrow crop choice and affordability issues. In contrast, local seed/grain markets, especially, can offer flexibility and speed through providing a wider selection of crops and varieties and the ability to source from distant locations, though transferring information about variety identity and adaptation remains an issue (Sperling and McGuire, 2010b).

Formal multiplication schemes for most key crops are at the initial stages of development. Efforts need to be made to widen release criteria: (a) to accommodate a stress tolerance versus yield trade-off (e.g. drought over brute production) and, (b) to allow for more specific adaptation to highly vulnerable areas. In addition, there has to be some initial and deliberate commitment to multiplying up breeder and foundation seed (in formal systems, these are the first generations in seed production, needed as the base for producing certified seed; breeder and foundation seed are usually produced by research organizations to specified purity standards). This is important so that organizations and entrepreneurial individuals have the core supplies they need to continue decentralized multiplication schemes that can render stocks available in multiple zones.

Ultimately, the bulk of activities that will make seed available have to reside with the informal sector, which serves more farmers and which has more agility. Traders here are particularly key as decentralized multiplication has to be linked to local demand.

In the immediate post-shock period, constraints to the availability of seed in local markets need to be better understood, including actions to address widening the scope of markets (seed/cuttings on offer) and identification of key varieties that can move between regions. Insights from a GIS analysis during the Kenya 2011 drought showed that traders can and do source grain that can be used as seed (i.e. 'potential seed' – Sperling and McGuire, 2010b) over relatively impressive distances. For instance, cowpea, pigeonpea and greengram crops and varieties adapted for the Tharaka region were sourced from areas over the Tanzanian border, some 300 km away (CIAT et al., 2011a).

On a more consistent basis, in the medium term, traders moving potential seed need to be explicitly and systematically linked to novel research products and to skilled farmer multipliers and cooperatives that can then scale up seed supplies relatively quickly.

(iii) *Securing access* to seed, including for more vulnerable groups.

Access is also essential for resilience, as farmers can only benefit from useful seed types if they can obtain the planting material. SSSAs highlight that access is the most common limiting factor to seed security. A resilience perspective on access supports the coexistence of multiple channels, formal and informal, with efforts to improve affordability, inclusion of diversity, geographical reach, and information transfer.

During a stress period, in the short-term, humanitarian provision of vouchers and cash for seed purchase, targeted to the vulnerable, has been shown to be a useful way to improve access (Bramel and Remington, 2004). Also, local actors themselves have been able to respond in numerous ways, and more systematic engagement with informal market systems can enhance potential for rapid response across scales and for reaching those excluded from more formal-sector channels. Hence we see how traders in northern Mali and across South Sudan have been key for giving seed credit in difficult periods (CIAT et al., 2011b; CRS and Partners, 2006), and how a vibrant barter economy emerged in Zimbabwe during the absence of a valid currency (CIAT et al., 2009).

In the medium term, both formal and informal channels might usefully be reviewed so as to enhance elements that help improve farmer access. For formal channels, mapping the geographic placement of agro-dealer outlets, and explicitly adding outlets in less served areas, can be critical for widening farmer access (Farrow et al., 2011, for Malawi). Further, putting new varieties on offer in small (<100 g) packet sizes makes seed more affordable for farmers, lowering the cost of experimenting and allowing even the poor to try new germplasm (PABRA/KARI/CIAT/TLII, 2010; Sperling et al., 1996). Note that the small seed packet model allows new varieties to be promoted through many channels, such as informal markets or village shops, which again brings new options geographically closer to farmers, improving access.

Informal channels and especially seed/grain markets already reach farmers in most parts of the world, including stress regions. The challenge is to ensure that innovations and improvements are consistently linked with formal mechanisms. Here the potential roles of traders in moving new varieties, working to improve seed quality, and passing critical seed information all need to be reinforced. Experiments to improve quality of trader seed (tracking provenance, keeping varieties separate, and ensuring good storage conditions) have had some initial positive success (McGuire and Sperling, 2008). Getting traders more 'variety literate' can also be accomplished by systematically linking them to extension information and to the normal field day (etc.) opportunities that formal dealers are accorded.

What is particularly heartening within this thrust of resilience and improving access is that many actions for broadening access in formal and informal channels are known and tested, for both short and medium-term responses. Simply, they need to be institutionalized and scaled up.

(iv) *Fostering information systems* that strengthen farmers' ability to strategize – and deal with fluctuations.

Access is not just about physically obtaining seed, but also the information associated with its use (McGuire and Sperling, 2011). In fact, information is perhaps *the* most important variable for enhancing farmers' seed system resilience: with information, they can shape demand for products and encourage the development of more supply-responsive channels. With agile information, farmers can change and alter their intra- and inter-seasonal response strategies.

Conventional extension, with its linear transfer of technology (ToT) has had limited scope for interactive learning (Biggs, 1990). In the short-term, more innovative uses of media, for example, radio (Seeds of LIfe, 2012) or SMS can improve communication about varieties that might be immediately available or newly emanating from research. Certainly, SMS recently functioned well in Haitian IDP camps where information and even cash were transferred via mobile phones (http://www.irinnews.org/Report/90319/HAITI-SMS-ing-preparedness). Experts also exist in informal channels who have extensive knowledge about provenance and adaptation of the (farmer) varieties on offer; explicit support should be given to these local individuals to aid in information sharing.

In the medium-term, encouraging the development of 'resilience-linked information systems' is a huge area of action. Information needs to be put in forms that facilitate agile thinking and maneuvering: there is not one simple 'package message' or 'package technology' which helps build resilience. In terms of seed security per se, farmers' ability to strategize depends on more than germplasm supply. They need information and support for innovation along multiple axes: (i) awareness of new varieties; (ii) insight into their suitability for stress; (iii) access to the material, along with the information; (iv) an ability to assess and experiment with materials in timely manner; and (v) an ability to share information with others so as to build repertoires over time. Information systems will need to be developed that respond flexibly to all aspects of this information sequence.

In terms of interactive information conduits, there have been wonderful advances in the last decade. Research and development (R&D) innovations platforms are being developed (Tenywa et al., 2011) and information technology advances – especially mobile phones and SMS – now mean that millions (billions?) of farmers can quickly get information pieces (within seconds), even if the two-way feedback systems are weak (see Baldauf, 2011, for an example for Kenyan cattle). These advances now need to be built in a consistent manner.

Lastly, perhaps one of the biggest gaps for promoting a resilience information portfolio exists with the mainstream more global shock-related information systems. The early-warning systems, as just one example, are shaped to report stress – for instance, drought, grain price rise – but not to capture response opportunities. Might they be technically reshaped to suggest also what is 'going well' and 'that which can be leveraged', and to do this in real time?

(v) *Enabling systems evolution* – developing space for new repertoires and opportunities.

As a final thrust, new livelihood repertoires will have to round out a more resilient seed system repertoire. For instance, across SSSA sites, development of novel agricultural product and processing opportunities can quickly steer seed systems in new and quite profitable ways, such as the development of cassava flour and products in Eastern and Coastal Kenya and Southern Malawi (CIAT et al., 2011a,c) or rural commerce expansion in Haiti (CIAT et al., 2010). Actions such as expanding opportunities for credit (e.g. Village Savings and Loans or microfinance) or providing sharp business and market skill development (Ferris et al., 2006) will likely prove as important for ensuring flexibility and durability in agricultural and seed systems as more crop-variety-seed-focused initiatives themselves.

In sum, building resilience in seed systems means building up a set of reserves of knowledge and action possibilities, and helping to ensure their availability and accessibility in a timely manner. The well-known adage 'knowledge is power' is *the* key to resilience response: usable, strategizing knowledge is central to farmers' survival and prospering in variable times in the face of dynamic challenges. The 'one shock' needs 'one response' mentality might best lain by the wayside. There will be on-going stresses and shocks, and a one-time action plan (even for urgent action) might best be viewed with caution.

6. Reflections and conclusions

Presenting four summaries of Seed System Security Assessments (SSSAs), this article gives rare insight into what happens to seed systems during different kinds of 'shock periods': political and civil conflict, drought and earthquake. Perhaps counter to common wisdom, seed systems prove to be relatively resilient, at least in terms of meeting farmers' planting needs for the upcoming season. In the short-term, systems absorb the shocks by drawing on social and technical repertoires: farmers alter crop profiles, make weighted use of multiple delivery channels (especially shifting toward markets), and innovate (e.g. with new barter mechanisms). Cross-scale linkages also become more prominent, as traders move seed supplies across longer distances and as they aim to match seed adaptation needs from far-removed source zones to zones in which materials will actually be planted. So stores of technical knowledge (social memory), multiple and flexible solutions, and cross-scale operating systems prove key for seed system resilience in the short-term. (Of note is that direct seed aid, the dominant humanitarian response for short-term seed security, seem at odds with all these resilient features: single option, no farmer strategizing, no feedback loops, and non-use of sustainable channels.)

Despite short-term survival, in the medium term, seed systems will have to be reinforced and transformed to address the inevitable fluctuating agro-ecological and farming system changes, partially shaped by climate change processes. Both the formal systems and informal systems will have to be subjects of significant modification (and some 15 practical actions are recommended in Section 5, incorporating the broader principles introduced in Section 3).

Formal seed systems on their own will have limited ability to address the full sweep of challenges. Indeed, even today, despite important donor investments, formal systems generally fail to serve the majority of farmers, with the notable exceptions of maize and exotic vegetable seed. Within a resilience framework, formal systems will have to take on unique, niche-like roles, especially in terms of catalyzing the first steps in a series of seed chains. Among other roles (see Section 5): formal systems should take lead in generating new and varied germplasm targeted for key stresses; they will have the challenge of better characterizing germplasm adaptation limits, for new and, perhaps, also for select local germplasm; and they should bear the responsibility for multiplying first generation seed (both breeder and foundation) to facilitate subsequent decentralized seed multiplication and delivery schemes.

The onus of resilience response will have to lie with the seed systems that farmers use for most of their seed, that are able to supply crop and variety diversity, that operate over large geographic expanses, and that can respond to rapid change: the informal systems. Informal systems, and especially local markets and their traders, will have to undergo significant transformation to meet effectively a resilience agenda. Among other key actions (see Section 5): traders will have to be engaged to better understand potential seed source zones; they will have to be encouraged (possibly with financial incentives) to raise and maintain seed quality across their range of agricultural wares; and their roles in passing on novel crop/variety products will have be broadened and made a great deal more dynamic.

However, perhaps it is at intersection of formal and informal – and where they both presently show marked gaps – that the greatest advances have to be made. Farmers need information to make informed (best guess?) decisions, to deal with unpredictable farming system environments and respond to longer-term environmental change. They need to understand the trends, the options for response to those trends, and the associated risks and benefits which might emerge as outcomes. Developing resilience-linked information systems will demand changes in: how information systems interact with farmers (i.e. empowering perspectives are key); the tools they use (i.e. interactive, allowing feedback, quick); and the content of what is shared (not simple production/promotion messages).

Taken all together, these actions point to profound changes in conventional seed security response. Information and skill enhancement become as important as seed production and delivery. Overall aims should shift, from a production–modernization focus to a production-stability and resilience focus. The locus of activity should move, from a formal system fixation to an expanded, complementary and rigorous focus on informal systems and especially on local market functioning. New key partners will emerge (e.g. traders) and even the criteria through which success is measured will need to be altered (Sperling and McGuire, 2012).

Seed systems, one of the key areas for promoting food security, can be strengthened to respond to the inevitable shocks and continuing agricultural stresses of the near future. However, to achieve production stability and gains, resilience has to be the central organizing principle, starting even in short-term response.

Work on seed systems also points to more general processes that are central for building resilience in other development sectors. (i) Options need to be developed/put on offer which anticipate varied fluctuation scenarios. (ii) Such options must be made available across geographic and temporal scales (and in time to be implemented). (iii) A diversity of supply or delivery channels should be reinforced to ensure wider access to technologies and strategies. (iv) The divide between formal (outside) and informal innovation systems might best be re-weighted, with both having key importance and processes promoted to ensure their smooth interface. (v) Finally, information – refined dynamic and ongoing – needs to form the heart of any technical response, so users can make informed decisions about qualities of performance, possible risks and emerging opportunities.

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