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What Do Complex Adaptive Systems Look Like and What Are the Implications for Innovation Policy?

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WHAT DO COMPLEX ADAPTIVE SYSTEMS LOOK LIKE AND WHAT ARE THE IMPLICATIONS FOR INNOVATION POLICY?

Andy Hall[i] and Norman Clark[ii]

Abstract

This paper explores the use of complex adaptive systems theory in development policy analysis using a case study drawn from recent events in Uganda. It documents the changes that took place in the farming system in Soroti district during an outbreak of African cassava mosaic virus disease (ACMVD) and the subsequent decline in cassava production — the main staple food in the area. Resultant adaptation impacts are analysed across cropping, biological, economic and social systems each of which operate as an interlinked sub-system. The policy implications of this story suggest a policy agenda that recognises adaptation capacity as the life blood of complex adaptive systems. Since these types of systems are found in all realms of human activity, it follows that strengthening this capacity is a key developmental priority that requires linking together new configurations of actors and resources to tackle an ever-changing set of contexts.

Key Words: Complex Adaptive Systems, Innovation Policy, Uganda, Cassava, Adaptation Capacity, Smallholder Production, Policy

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I. INTRODUCTION

The use of complex adaptive systems perspectives to help understand and shape the world around is not new. Indeed there are long-established communities of practitioners and researchers that have been working with these ideas for many years and trace their theoretical roots to the work of scholars like Lotka and von Bertalanffy in the 1920s and 1930s. What prompts us to write this paper, however, is that complex adaptive systems perspectives have begun to re-appear in both the agricultural and general development literature[iii]. As scholars of innovation studies — a discipline where complexity has been a core analytical perspective for the last 20 years, at least — we view this as a positive trend. But we also have a sense of *déjà vu*. Critically, we remember how our own enthusiasm for the conceptual aspects of an *innovation systems* perspective tended to obscure rather than clarify what complexity looked like in practice. And equally important, we remember struggling to bridge the gap between a conceptual understanding of the innovation process (albeit an empirically-based conceptual understanding) on the one hand, and debates and policies in implementation arenas (particularly donor activity) on the other.

Of course, prompted by many calls to explain what should be done "on Monday morning" we did (and continue to) suggest how innovation systems ideas can be used in agricultural and rural development practice (one response was published as World Bank, 2006; see also Hall et al 2008), Nevertheless, the topic of complex systems, with all its seductive traps for conceptual musing, still needs to rise to the challenge of demonstrating what practical additionality it can bring to mainstream development policy and practice. The term 'mainstream' here is important because the challenge really is about penetrating what, in many senses, are the bastions of non-adaptive, non-complex systems organisations. The strategy may well be one of determining what room for manoeuvre exists.

The purpose of this paper is, therefore, twofold. Firstly, it is to illustrate what complex adaptive systems look like in action, and, secondly, to illustrate and discuss the additionality that this type of analytical perspective brings. The illustrative example chosen is a historic case of a crop pest

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[iii] See, for example, The Broker (2008), Ekboir et al (2009), and Ramalingam et al (2008)

outbreak that took place in the early 1990s. It documents the changes that took place in the farming system in the Soroti district of Uganda during an outbreak of African cassava mosaic virus disease (ACMVD) and the subsequent decline in cassava production — the main staple food in the area.

In particular, the case explores the path-dependent set of adaptations that took place in cropping patterns, food consumption practices, economic activities and social relations — each of which operated as an interlinked sub-system. The analysis identifies the farmer at the centre of an evolutionary mechanism used to cope with change. We believe the strength of the mechanism observed is that it takes an implicit systems approach to problem-solving and coping with unpredictable change. The story does not suggest that such mechanisms are a panacea to rural development; indeed, this is really a story of adaptation simply in order to survive the loss of the main source of food in the area. Rather, it is the story of a promising innovation process that could be built on, but instead was invisible to efforts to address a major food security crisis. The main thrust of the policy implications of this story suggests a policy agenda that recognises adaptation capacity as the life-blood of complex adaptive systems. Since these types of systems are found in all realms of human activity, it follows that strengthening this capacity is a key development priority that requires linking together new configurations of actors and resources to tackle an ever-changing set of contexts.

Our main message is that if policy engages with complexity — and we believe there is no other choice than to do so — it will need to focus much more on strengthening capacities and processes in order to better cope with unforeseen change. This is innovation capacity. Such capacities need to act locally. But they also need to comprise much more than farmers' actions in the rural space, and need to draw on a much wider set of knowledge-based resources that are institutionally and geographically diverse and dispersed. Research is part of this. But what is also important is that this perspective opens up a range of other options for interventions to deal with unpredicted shocks, which go beyond a knee-jerk reaction of funding more research or supplying emergency relief. This resonates with global policy perspectives that have shifted from an emphasis on science and technology to one on innovation, where research is seen as part of a wider set of creative capacities.

Returning to our specific case, in our view it illustrates how innovation comprises a series of small technical and non-technical changes that take place as a response to a changing environment. This is not a new finding, but it illustrates neatly what the process looks like — a complex adaptive system in action. We believe the message of shifting to a capacity strengthening agenda, in the widest sense, to be the main message not just of this paper, but of the whole family of systems concepts that circulate in the development community; it should be used as a rallying point to help these perspectives link up and leverage change in the mainstream. We preface our case with an introductory overview of some of the key themes in the complex adaptive systems literature.

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II. COMPLEX ADAPTIVE SYSTEMS

The use of complex adaptive systems analysis has now begun to re-appear in development literature, though the idea itself has a long pedigree, dating back more than 70 years. For example, Latke and von Bertalanffy began to develop an open systems perspective on all science in the 1920s and 1930s, while Emery, Beer, Ashby and many others did a great deal of valuable work later on in applying systemic ideas to a wide range of disciplines[iv]. More recently the notion of an "innovation system" has also begun to appear in the technology development literature, although it is seldom related directly to general systems theory[v]. We do not intend to engage directly with what is obviously a long academic tradition. Nor do we believe that there is one definition of a system that is necessarily *the* correct one. We do feel, however, that there are important analytical reasons for setting out as clearly as possible our own views regarding the intrinsic nature of a "system". All too often there is a tendency for policy analysis to retreat back to a single discipline, with the inevitable result that such analysis often fails to capture the holistic nature of problems and solutions. Also, sometimes the concept of a "system" is used, but rarely is it defined and independent of its context. Often, the reader is left wondering what precisely the nature of such a system is, what it consists of, how it may be identified, how it may be classified, how it behaves, etc.?

The essence of systems thinking can be summarised in the following way. *Firstly*, at a broad descriptive level a system may be defined as an entity made up of interconnected elements, and one that has a boundary that separates the inside from the environment. Often a distinction is drawn between a closed system and an open system, based upon the extent to which the analyst wishes to consider the degree of interaction with the system's environment. When the system is open both matter and energy can enter and leave the system. In the human or life sciences, however, in addition to these broad distinctions (which often actually help to define a system in the physical sciences as a closed one), we have three additional requirements. Firstly, the interacting elements that make up living systems are connected in an organised manner. The components are affected by their participation, and are modified when they leave the system.

[iv] For a detailed exploration of the applications of systems theory to economic change, see Clark and Juma (1992) and Clark, Perez-Trejo and Allen (1995). Earlier work on general systems theory may be found in Emery (1970) and Koestler (1970)

[v] See Clark (2002) for a detailed discussion of this and related points

A *second* property of living systems is that their behaviour cannot really be understood solely by formal analysis of their component parts. Instead, they have to be understood as whole entities with their own idiosyncratic properties. Reduced analysis can often help, of course, but it cannot comprehend the totality of system behaviour. Indeed, it is often the continuous exchange of resources and information among its components that drives system behaviour.

Thirdly, living systems are evolutionary. They do not return to states of equilibrium like mechanical systems, but continuously change in structure and behaviour over time. It follows that the dynamics of such systems cannot be completely understood either from descriptive studies or as equilibrium systems. Instead they should be seen as a series of unpredictable responses to events where a critical role is played by feedback mechanisms, which act to amplify, or reinforce human, biological, physical or socio-economic processes (Allen and Varga, 2006).

Fourthly, an important characteristic of living systems is that their dynamics are strongly influenced by the spatial patterns of their components. Interactions between and among different spatial and temporal scales may be thought of as comprising a hierarchy of organisational levels, such that processes operating at one level are only partially autonomously defined, because processes operating at other spatial or temporal scales can affect their dynamics and their stability (Koestler, 1970). This, in turn, is closely related to 'systemic resilience' — the ability of the system to maintain its structure in the face of disturbance (Holling, 1985). But it is also a property that allows the system to absorb and utilise change. Putting it differently, we are not referring to the system's ability to return to a hypothetical equilibrium state in the face of disturbance. Rather, we are referring to its ability to explore possible evolutionary pathways that it could follow, defined in terms of different regimes of operation (Allen, Strathern and Varga, 2008). Resilience, in a complex systems perspective, extends, therefore, beyond the measure of what has been defined as 'return time' to a previous assumed equilibrium state.

Finally, systems are often discussed in terms of their complexity — the degree to which internal components and their interactions become increasingly numerous over time, requiring, in turn, greater degrees of organisation. Very recently authorities such as Allen *et al* (2009) have begun to use the term to differentiate evolutionary systems thinking from the more mechanistic "systems dynamics" that was fashionable in the early 1970s. Our use of the term 'complexity' will follow Allen's interpretation.

In terms of complex systems theory, therefore, we define an innovation system as both an *"economic"* and a *"knowledge"* system with flows of resources and information taking place among its component nodes and across its boundaries. The resource flows comprise finance, materials and labour inputs. The knowledge flows included formal and tacit knowledge. They also included "learning" about how to scale out technology at a decentralised level. Such innovation systems are *evolutionary* since new knowledge is constantly entering the system and leading to behaviour modification. There is no return to a previous equilibrium. They exhibit *complexity* in that knowledge and resource flows that are moving across many stakeholder groups. This, in turn, requires *organisation* to minimise and manage complexity. Systems are normally *adaptable* and *resilient* while resources flow across their boundaries. They behave *holistically*. In other words, they behave as a totality and therefore, analytically, their behaviour cannot be reduced entirely to that of component nodes. Finally, they usually engage in *networking* designed to facilitate information interactivity that improves system efficiency.

III. CASE STUDY

The story of the evolutionary nature of a food system, which was witnessed in the Soroti district of Uganda, emerged during a post-harvest needs assessment survey of sweet potato farmers conducted by one of the authors in 1994. The survey was part of a wider study seeking to understand the post-harvest needs of sweet potato farmers in eight districts in Uganda and to use the information gathered to guide technical interventions and further technical research (see Hall 1995). Information was collected from farmers using group discussions and individual interviews. The approach of the survey was to gain an understanding of the post-harvest constraints for sweet potato in the context of the wider food system. In most of the districts covered by the study (with the exception of Soroti district) it was found that sweet potato post-harvest systems were well-adapted to the demands of local conditions and the role that the crop played in the food system. In fact, it was difficult to see ways in which technical interventions could provide improvements that would be of such significance to prompt adoption and a change of practice on the part of farmers. This is not to say that the food system was static, it had clearly evolved over time to meet local contingencies (see Hall 2000); however, this change had been gradual — probably since the introduction of the crop 150 years previously.

The story in Soroti district was radically different. The role of the crop in the food system had changed significantly in the previous 10 years because of a disease outbreak in a major food crop in the area. Associated with this, choices of varieties and food habits had changed in ways that had not been witnessed anywhere else in Uganda. The case was notable for two reasons; the changes that had taken place had precipitated a weakness in the post-harvest system, which farmers could not totally cope with, and therefore demonstrated a clear need for technical intervention (new storage technology). The other notable feature of this case was that it clearly demonstrated the sequences of adaptations that farmers made to cope with change in their food system and provides an insight into the mechanisms by which these systems evolve.

During the 1960s and 1970s the main cash crop in Soroti district was cotton. Cassava at this time was grown as a food crop, and was the traditional starch staple of people in the area. Cassava was well adapted to this role in the climatic conditions of the district, which are characterised by a long dry season. The relative drought resistance of the crop allowed it to provide a year-round supply of roots. Consumption of cassava was in two forms; fresh roots were cooked by steaming or boiling. Alternatively, it was also dried throughout the year to make chips, which were subsequently pounded and ground to make flour. The flour was then used in combination with millet flour to produce a stiff porridge or “bread” known as *atapa*. With the collapse of the cotton industry in Uganda, farmers were forced to seek alternative cash crops. Consequently, during the early 1980s cassava become increasingly important, both as a major source of income as well as food.

ACMVD infection first became apparent in Soroti district in 1986. The intensity of the infection increased in the following years and according to farmers, by 1988 cassava production was severely reduced. Table 1 presents production figures for major starch staples during the period.

TABLE 1: PRODUCTION TRENDS OF THE MAJOR STARCH STAPLES IN SOROTI DISTRICT (1985-92)

	1985 (Ha.)	1986 (Ha.)	1987 (Ha.)	1988 (Ha.)	1989 (Ha.)	1990 (Ha.)	1991 (Ha.)	1992 (Ha.)	1993 (Ha.)
Sweet potato	16,221	8,679	5,462	10,150	9,226	6,613	15,424	19,020	16,421
Sorghum	16,582	10,261	8,967	11,181	11,440	12,378	17,442	16,532	11,207
Maize	3,216	2,002	879	1,263	1,252	1,278	3,139	2,464	2,071
Cassava	19,347	10,337	8,672	*	15,565	16,734	15,899	3,797	4,455
Millet	39,271	25,317	25,094	26,207	31,647	34,812	31,132	15,346	12,575

Source: Agricultural census of Uganda, 1993
** data missing*

With the emergence of ACMVD, farmers were faced with the problems of finding an alternative crop as a source of income as well as a year-round supply of food. These problems were compounded by the almost total loss of cattle and, therefore, draught power in the area due to theft during a period of civil insecurity. The farmers’ answer to ACMVD was to substitute sweet potato for cassava. Prior to the emergence of ACMVD and the decline of cassava production, sweet potato had the role of a secondary food staple. It was eaten fresh between the months of July and November/December. Any surplus remaining would be sliced and dried into a product known as *amokegy*. Roots that were too small to slice and dry were crushed and dried to produce *ingingo*. Dried sweet potato was at this time consumed by simply boiling.

As a substitute for cassava, sweet potato has some of the same necessary characteristics — it is a starchy root crop with some tolerance to drought. However, it is not a perfect substitute as it cannot remain in the ground for the whole year and as a result it cannot provide fresh roots during the critical dry season. Farmers substituted sweet potato for cassava production in order to cope with the emergence of ACMVD, but there were a number of problems to be overcome. For example, the varieties of sweet potato grown at the onset of ACMVD were not particularly well-suited for drying and making into flour to use in *atapa*. Some sweet potato was marketed, but it was not a major cash crop. Sweet potato varieties were grown that matured late; after ACMVD emerged farmers needed to grow sweet potato varieties that matured quickly — both to provide food after the long dry season as well as to provide cash.

What then were the major types of adaptation required as a result of ACMVD? In our view they may be classified as follows:

i) Cropping systems adaptations

The most fundamental change that occurred in the cropping system was the substitution of sweet potato for cassava. Sweet potato changed from being a crop that was grown on a small scale, often in plots close to the home for household consumption, to a crop grown on an extensive scale for both sale and consumption. In addition, it became necessary to grow sufficient sweet potato so that an adequate surplus could be produced for drying and storage to provide food during the long dry season. Previously, cassava accounted for a large proportion of the food eaten in this period. The lack of cassava also had consequences for the relative importance of other crops, particularly millet and sorghum. In the past millet had been grown for making a flour that could be mixed with cassava and sorghum for brewing into local beers. The decline in the production of cassava was mirrored in the decline in millet production (see Table 1). With no cassava at the end of the dry season, this became a time of extreme hunger. Sorghum, and to a lesser extent millet, was now eaten at this time rather than brewed (see social system adaptations). Farmers adapted the cropping system so that millet and sorghum were dry-planted during February so that they would germinate with the first rains in March and provide food as quickly as possible; these crops have shorter maturity duration than sweet potato.

Farmers also indicated that the changes in the cropping system had, in some way, altered the performance of sweet potato in terms of yield. A comment that was repeatedly heard from farmers was that since ACMVD had virtually eliminated cassava, the yield of some varieties of sweet potato had improved. With the evidence available it is difficult to provide a conclusive explanation of this observation. Possibly, the absence of cassava had resulted in sweet potato being grown on more fertile fields. This suggests that adaptations in the cropping system had implications for the biological system underlying production.

ii) Economic system adaptations

After the disappearance of cassava, sweet potato became the major cash crop in Soroti district. In contrast to cassava, sweet potato cannot remain in the ground throughout the dry season. As a result, unlike cassava sweet potato must be harvested and sold during October and November. This problem was made worse by the fact that urban consumers (and, therefore, sweet potato wholesale buyers) prefer one variety — *Osukut* (also known as Tanzania). This is an early maturing variety that is highly susceptible to sweet potato weevil attack. As a result of this susceptibility, farmers must harvest commercially grown sweet potato as soon as it is mature. This has two effects: the entire crop of sweet potato has to be sold during one relatively short period of the year (October-November); and, because all farmers face the same problem the market tends to be over supplied and the price drops. A limited number of farmers reacted to this problem by early and late planting in swamp areas so that they had sweet potatoes for sale during off peak periods (August-September and December-January). However, this option was not open to all farmers as swamp areas are limited, with access restricted due to private ownership. The farmers as individuals had no influence on the preferences of urban consumers, so they were forced to continue growing a sweet potato variety that was poorly suited to prevailing climatic conditions.

The sum total of all these problems with commercial sweet potato production was that it did not exactly fit the characteristics of cassava. This was originally sold throughout the year. In contrast, fresh sweet potato is generally not available for sale in the dry season, a period when the majority of the farmers’ expenditures need to take place. For example, school fees and poll tax have to be paid from January onwards, and health problems that often require ready cash tend to intensify in the dry season. In the past farmers had sold their cassava as expenditure needs arose. It was common to hear farmers refer to cassava as the “bank in the ground”. Farmers now had to adapt their behaviour to selling produce in order to provide cash, which might be needed at a later date or for a particular planned expenditure in the future. This obviously had a higher degree of risk — with farmers making themselves vulnerable to supply and demand fluctuations prior to having information on exact expenditure needs. When farmers’ commercial cultivation of sweet potato was first examined, it appeared that they were simply growing as much sweet potato for sale as possible and were not taking into account the planting patterns of other farmers in the area. On probing, it was found that they were aware that other farmers’ behaviour would affect the supply and price situation at harvest. At first it appeared that they were behaving rather incongruously, bearing in mind their generally risk-averse nature. However, it emerged that they had adapted their economic behaviour further. Farmers explained that if they were not able to sell their entire crop at a reasonable price, they would simply dry it and store it. This apparently served two purposes. The sweet potato would not be lost as it could still be consumed by the farm family. More importantly it could be bartered for services within the local community. Furthermore because of the increased importance of dried sweet potato (both *ingingo* and *amokegy*) in the dry season — there was almost nothing else to eat — the crop became monetised; it could be sold as a source of cash. In other words farmers had adapted to the lack of cassava as a cash crop in the dry season by selling a product that had previously been used predominately for home consumption. Furthermore this adaptation — because it included an element of storage — allowed farmers to reduce the risk associated with adopting a cash cropping strategy which would force farmers to sell perishable production in advance of information concerning expenditure.

iii) Social system adaptations

Of all the adaptations that farmers made, those which we have classified as social are the most deeply embedded in the other aspects of the farming system. For example, the need to sell both fresh and dried sweet potato described above required farmers to undertake essentially social activities to find and establish or strengthen new markets and outlets for the sale of sweet potato. Of the more interesting social adaptations, those associated with food preferences and habits, and those relating to the changing tasks of men and women are the most worthy of description.

The cultivation of sweet potato in Uganda is generally the domain of the woman of the house. Sweet potato is mainly grown for home consumption and it is the woman's role to provide food for the house. This is generally true for all food crops. Men become directly involved in cultivation activities when the crop is for sale or is grown for brewing purposes. Discussion with farmers made it quite clear that men had become closely involved in the cultivation and production of sweet potato since its commercialisation in Soroti district.

During the course of research on sweet potato in Uganda it was discovered that the best way to determine the involvement of men in production was to begin by asking them to identify sweet potato varieties in the field. Usually at this point the man would admit defeat and call for the woman of the house to answer our questions. This was not the case in Soroti. It is likely that the involvement of men with the crop had other consequences. Their involvement was likely to have increased the influx of new planting material. Men have much greater freedom to travel and, therefore, had the opportunity to collect new varieties. Although this may have happened previously, the commercialisation of the crop would have added fresh impetus to this endeavour. Men would have had greater access to information from the agricultural extension service and in general terms the profile of the crop would have been raised.

In addition to men adopting sweet potato as "their" crop, other gender-determined activities were altered and adapted. This was particularly the case with post-harvest activities. The most notable was the drying of sweet potato. Two forms of dried sweet potato are made — dried slices known as *amokegy* and crushed roots known as *ingingo*. Traditionally in the production of *amokegy* the peeling of the roots was done by women and the slicing was undertaken by men, using a purpose-made, long-handled knife fixed in the ground. Now that there was a greater need to slice *amokegy* both men and women undertook this task. In the case of *ingingo* both the peeling and crushing was undertaken by the women. Now that *ingingo* was the major dry season food, considerably greater quantities needed to be produced. Again the crushing was now shared by both men and women. Although these changes may seem trivial, in the context of a social system where gender-determined tasks are strictly adhered to, these changes represented a major adaptation.

Food habits and preferences are another aspect of rural life in Uganda that is deeply embedded in the social system. Farmers still said that cassava is “our food”. Prior to the decline in cassava production the major staple was cassava flour mixed with millet flour, which made a type of “bread” known as *atapa*. Sweet potato was dried and sliced for emergency consumption in the dry season. *Ingingo* was also made on a very limited scale for dry season consumption. The decline in cassava production almost completely deprived farmers of their traditional food. Not only did sweet potato have to replace cassava production, but the way it was consumed had to also be adapted. Farmers substituted sweet potato flour made from *ingingo* for cassava flour. (As will be seen below this caused farmers to look for sweet potato varieties that were good for *ingingo*) This required that *ingingo* be produced throughout the period that fresh sweet potato was available, rather than only just before the beginning of the dry season.

In the *atapa* recipe, however, sweet potato flour was not a perfect substitute for cassava flour. When mixed with millet flour it did not produce *atapa* of the required consistency and elasticity. It was also too sweet. Farmers had to adapt the recipe. They found that sweet potato flour mixed with sorghum produced the desired consistency, and that the addition of green tamarind juice further modified the consistency and texture as well as reducing the sweetness. The culturally-determined necessity to eat *atapa* — even in the absence of cassava — was the impetus for farmers to experiment and innovate with the food that was available. In addition the consequences of not doing so — there was nothing else to eat — were great enough for them to adapt and change deeply embedded social norms.

Finally, with the absence of cassava and the diversion of sorghum to food consumption, adaptations had to be made to brewing practices. Farmers started to use sweet potato for brewing local beers and spirits. Often "time expired" *amokegy*, or *ingingo* that has become badly infested at the end of the dry season, was converted into alcohol. When cassava was previously available this would have been unthinkable. Farmers indicated that the brew produced was acceptable, if not quite as good as the old recipe.

iv) Biological system adaptations

By the end of the period studied farmers were growing 12 varieties of sweet potato, of which six had been adopted since the arrival of ACMVD (Table 2 on the next page illustrates the relative abundance of different varieties). Of the six varieties that farmers indicated as most abundant, the third, fourth and fifth were recent adoptions. Other recent adoptions were not grown in large areas, but farmers explained that these varieties were being tested. The variety grown on the largest scale was one grown for the market. This variety was popular before the arrival of ACMVD, although it had since been cultivated on a much larger scale due to its new economic importance.

TABLE 2: CHARACTERISTICS OF SWEET POTATO VARIETIES GROWN BY FARMERS

	Abundance (Rank)	**Years since adoption**	**Storability of dry slices**	**Storability of dried crushed**	**Yield**	**Early maturity**	**Remains in the ground after maturity**	**Good for fresh consumption**	**Drought tolerance**
Osukut	31 (1)	15	*	*	31	30	*	9	*
Haraka	3 (7)	1	*	*	*	*	*	*	*
Odopelap	21 (2)	20+	36	30	16	*	28	14	28
Etemokidula	1 (10)	20+	8	*	*	*	*	*	*
Ateseke	14 (3)	4	*	37	36	47	*	*	*
Okunguruder e	2 (9)	3	*	*	*	*	*	*	*
Ongada	11 (4)	2	13	18	*	*	54	*	41
Esamait	3 (7)	40 +	22	*	*	*	*	*	*
Etamu	8 (5)	2	15	15	*	*	18	29	20

Emeketa	6 (6)	40 +	6	*	17	23	*	48	11
Total	100	--------	100	100	100	100	100	100	100

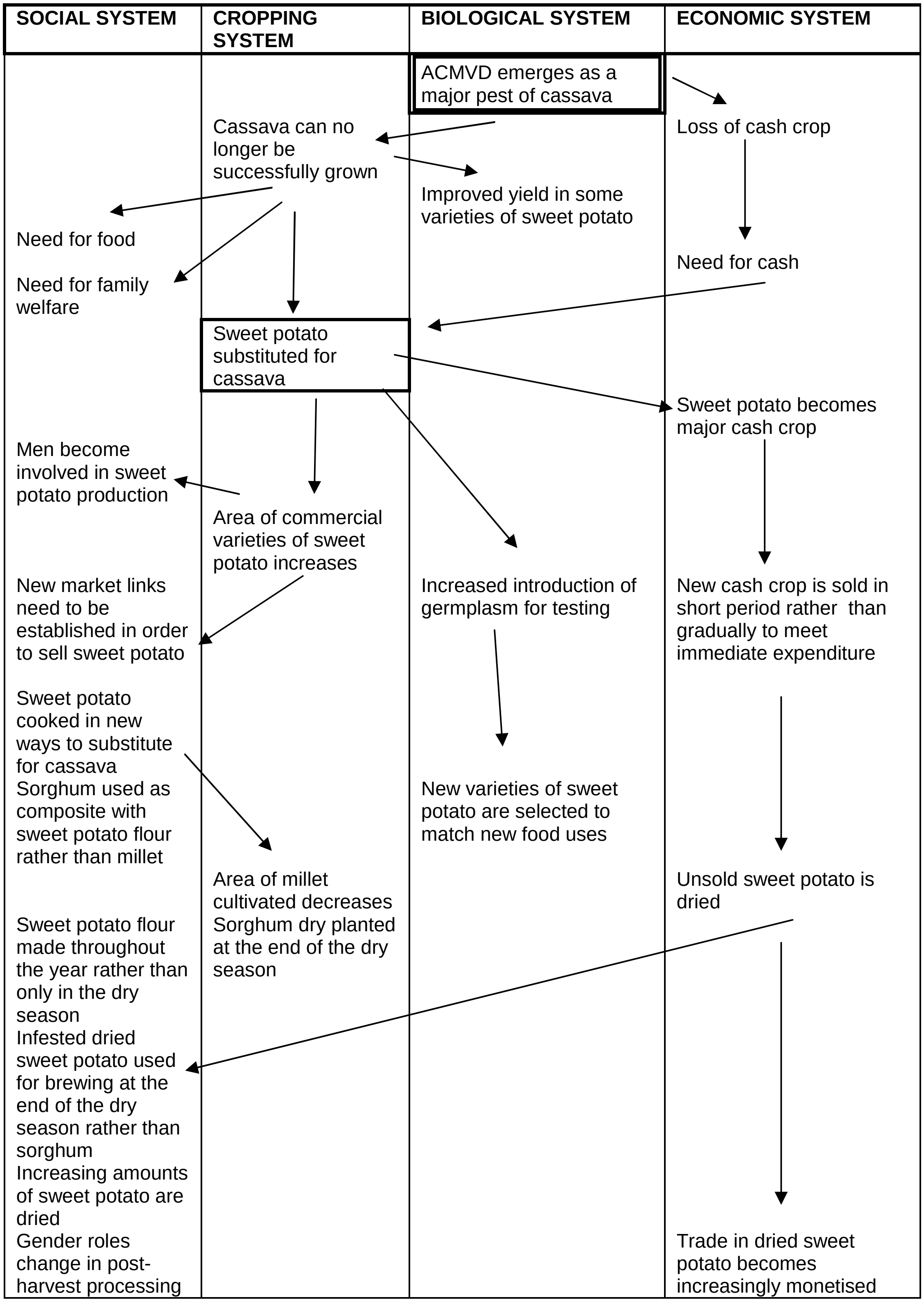
Source: Scores provided by a group of 50 farmers in variety matrix PRA exercise in Acaboi village, Soroti district.
** indicates that farmers did not differentiate between varieties for these characteristics*

The third, fourth and fifth most abundant varieties, which were recent adoptions, were ones that farmers picked as good for producing *ingingo*. As described above, the production of *ingingo* was of minor importance when cassava was available. However, as it subsequently became a component of a major staple food the importance of this characteristic increased. Of the varieties grown prior to ACMVD only one was perceived to possess this quality. Table 2 summarises the characteristics of varieties grown by farmers and their adoption history.

These changes in the varieties chosen and the changes in area allocated to varieties — notably Osukut — mirror the changes that needed to take place in the other areas of the farming system. Farmers indicated that the new varieties they were growing were collected from neighbours, and friends from other areas of Uganda. This was part of a process routinely observed in sweet potato farmer fields, wherein farmers tested out new material they had gained access to. Varieties that farmers considered to be good "performers" were adopted. What is interesting is that the contingencies arising in the economic and social system due to ACMVD, and the changes they caused in the cropping system, directed farmers to value a new set of attributes in their evaluation of new varieties, while giving impetus to the intensity of their experimentation. In other words, the selective pressures that determine the characteristics of dominant varieties are part of a continuum that stretches right across the sub-systems of the farming system. This suggests that farming systems are truly evolutionary, where the farmer affects adaptation based upon a need to survive in a changing production environment. If this is the case, it is helpful to draw out some of the important features of the evolutionary mechanism.

The interconnectedness of these different sub-system changes, and the pattern of evolution that this leads to, is illustrated in Figure 1 (see following page):

FIGURE 1: THE EVOLUTION OF THE FARMING SYSTEM IN SOROTI IN RESPONSE TO ACMVD



SOCIAL SYSTEM	CROPPING SYSTEM	BIOLOGICAL SYSTEM	ECONOMIC SYSTEM
		ACMVD emerges as a major pest of cassava	
	Cassava can no longer be successfully grown		Loss of cash crop
		Improved yield in some varieties of sweet potato	
Need for food			Need for cash
Need for family welfare			
	Sweet potato substituted for cassava		
			Sweet potato becomes major cash crop
Men become involved in sweet potato production			
	Area of commercial varieties of sweet potato increases		
New market links need to be established in order to sell sweet potato		Increased introduction of germplasm for testing	New cash crop is sold in short period rather than gradually to meet immediate expenditure
Sweet potato cooked in new ways to substitute for cassava			
Sorghum used as composite with sweet potato flour rather than millet		New varieties of sweet potato are selected to match new food uses	
	Area of millet cultivated decreases		Unsold sweet potato is dried
Sweet potato flour made throughout the year rather than only in the dry season	Sorghum dry planted at the end of the dry season		
Infested dried sweet potato used for brewing at the end of the dry season rather than sorghum			
Increasing amounts of sweet potato are dried			
Gender roles change in post-harvest processing			Trade in dried sweet potato becomes increasingly monetised

IV. NEW INSIGHTS FROM A COMPLEX SYSTEM ANALYSIS

The above discussion of the ACMVD outbreak in Uganda is markedly different from the majority of published accounts (see, for example, the special issue of *Tropical Agriculture* cited in the references below). Other accounts focus on either the effects of the disease on cassava production; the epidemiology of the virus; or the advances made in strategies to combat the disease either through cassava varietal selection or through improved pest control measure. These accounts are, of course, important and have value in advancing knowledge on the disease and its control.

Our account, however, is different. It explores the human-crop-disease-environment interface and tries to understand the nature of the change process. That interface is agriculture and that change process is agricultural innovation and development — a topic that has exercised the minds of researchers and planners for the last 50 years in Sub-Saharan Africa. What our account tells us is that left to their own devices, farmers cope with major shocks to their livelihoods (in this case a major pest outbreak in a staple crop) by mobilising whatever ideas and resources they have at hand to adapt the way they produce and consume their food and earn an income. These are not simple or perfect changes, but an interconnected set of responses that go beyond (although include) changes in production and post-harvest technology in order to survive a difficult situation.

We are not the first to observe this sort of phenomenon. For more than 20 years the farmer participatory technology development movement has been arguing that farmers need to be put at the centre of the development process — the Farmer First approach (e.g., Chambers and Ghildyal, 1987, and more recently Scoones and Thompson, 2009). Such a perspective has, in recent years, been reinvigorated through the movement for the promotion of local innovation (PROLINNOVA, see Sanginga et al 2008).

The Soroti case, however, demonstrates that while these perspectives have got some things right — farmers are capable innovators — they have also got some things very wrong. There are limits to the creative, adaptive capabilities of farmers and while they survived the ACMVD outbreak, the adaptations that they had to make in their food consumption practices were miserably unpalatable and only took place because the alternative was starvation. And while our case demonstrates the importance of farmer-led innovation and farmer-to-farmer transmission of ideas (and varieties in this case) the farmers in our story seem to have been totally isolated from other sources of creativity, information and resources. And this, of course, includes agricultural research, which is conspicuous by its absence from our story.

Stephen Biggs has long lamented the fact that farmers' participatory research tended to throw the baby (science) out with the bathwater (pers. Com.). Martin Bell insightfully noted that the promise of the indigenous knowledge movement never materialised because it failed to grasp that the real task was not to replace research-derived knowledge with local knowledge, but to blend the two for innovation (Bell, 2006).

So, how can our account of rural dynamics take the debate forward? We believe its contribution is that it evidences a capacity for change and adaptation and points to the centrality of this capacity in rural economies. Our account does not give primacy to technology as the driver of change, nor does it give primacy to the knowledge of farmers. Rather, while recognising the importance of these, it gives primacy to the capacity to respond to changing circumstance through adaptation and innovation. The account, however, also points to the inadequacy of this capacity in rural areas.

The way the farmers coped in Soroti was by no means a perfect or permanent solution, but it was the next best solution that could be put into place on its own to avoid severe food shortages.

We also believe that our account typifies dynamics that are at play across most aspects of all rural economies. Livelihoods of households and rural entrepreneurs are constantly under threat from unpredictable crop and livestock disease; unusual weather patterns; price changes and new economic conditions. Households and rural entrepreneurs make the best of these shocks by the sorts of adaptive processes we have described in the Uganda case. But these adaptive capacities have their limits. Conversely, these same households and entrepreneurs may see new market opportunities and adapt their activities accordingly. But these market-driven adaptive processes also have their limits — often because of the weak information networks in which small scale entrepreneurs are embedded (World Bank, 2006).

We, therefore, argue that what our account of the ACMVD outbreak contributes is not just that it neatly illustrates what complex adaptive systems look like in action. Rather, it also reveals the types of nascent capacity to innovate that exist and points to ways that these may be strengthened. For example, during the ACMVD outbreak the major public support to farmers was research on the disease and the multiplication and distribution of clean planting material. Our perspective would suggest that what farmers also needed was help from food and nutrition experts on how to reconfigure their food habits to best suit what was available. They needed help from sweet potato (not cassava) researchers on how best to adapt cropping patterns and select new varieties. They needed partnerships with the food processing industry to develop new commercial food products for sale. And, much more, besides.

In other words, a complex adaptive systems account of rural development, with its emphasis on processes and capacities, opens up a new range of options for supporting innovation and change. This is quite fundamental because not only does it suggest different and sometimes counterintuitive options — for example, tackling cassava disease outbreaks means working with the private sector on sweet potato product development — but it suggests a different role for policy. Whereas in the past policy was seen as a way of orchestrating socially useful innovation trajectories, the revealed reality of cases like ACMVD suggests that the role of policy will be to identify emerging nascent capacities and trajectories and support them. This presents some considerable challenges for public policy. For example, what might the role of extension be in this sort of situation? We suggest probably less in terms of transferring research products and technologies and more in terms of helping network farmers into additional sources of ideas, including those from research scientists; in other words, brokering farmers' connections into a wider set of expertise. This, in turn, requires that institutional settings of scientists need to change to make them less isolated and more responsive to new demands.

V. CHALLENGES FOR PUBLIC POLICY

In this last section we reflect on what our insights from the complex adaptive systems account of ACMVD might mean for public policy. In the earlier era, innovation was equated with technology development and capacity was equated as research capacity. At that time policy proscriptions could simply focus on ensuring that sufficient resources were allocated to research and, in the same way, innovation performance could be tracked through indicators of research capacity and technology creation. The emerging reality of the innovation process outlined above not only reveals the inadequacies of this earlier policy perspective, but suggests that an altogether different approach is required.

First and foremost the signature of innovation performance is no longer the existence of technological artefacts or the expertise to produce these (important as they are). Rather, its signature is a process that is fit for the purpose of mobilising different pieces of information to resolve a changing series of challenges and opportunities. This means it is an adaptive process, where learning plays a large role. *Secondly*, the signature of innovation capacity is no longer single nodes of expertise and information in research organisations. Instead, the signature of capacity is a system of multiple nodes of expertise, where users of new products and services are prominent nodes in their own right. These arrangements are often informal, adaptive and transient.

Thirdly, the signature location of emerging innovation is rarely in the mainstream of public policy intervention or as a result of the initiatives of international development organisations, including the Consultative Group on International Agricultural Research (CGIAR). Increasingly the signature location of innovation is at the margins, “under the radar” of public policy and formal research organisations. The adaptation documented in our account of ACMVD is recorded nowhere else that we are aware of. Many of today’s development innovations emerged in this way. Examples include Systems of Rice Intensification (Shambu Prasad, 2007); Farmer Field Schools (see http://en.wikipedia.org/wiki/Farmer_Field_School); the commercialisation of spirulina (Prasad, 2005); treadle pumps (Hall et al 2007); micro-finance (see http://en.wikipedia.org/wiki/Microfinance); innumerable civil society-derived innovations in rural development (Raina, 2005) and a myriad of user innovations that are largely undocumented.

These “below the radar” innovations are important not just because of the specific new product or service that they lead to and the developmental impact these may have. They are also important because they represent new forms of innovation capacity that may have wider development significance. In other words these are new, contemporary modes of innovation that public policy needs to learn about and learn how to nurture. The challenge for public policy is therefore two-fold. Firstly, to find ways to be alert to emerging innovation practices that, by definition, are invisible to most mainstream thinking and sources of information that policy draws upon. Secondly, to find ways to provide the nurturing environment that can move these new products and services and new innovation capacities from the margins to the mainstream and, in so doing, accelerate the learning process through which innovation capacity is enhanced. An implication of this is that public policy needs to shift from an orchestration role in which it sets the conditions from which innovation will emerge, to a more reactive role where it supports new patterns of innovation behaviour.

Of course, we are not the first to say this. For example, Alsop et al. (2000) made a similar point in their discussion of coalitions of interest around agricultural development in India. The *Convergences of Science* Programme of the Wageningen Innovation and Communication Group makes similar points (see http://www.inref.wur.nl/UK/Research+Programmes/Convergence+of+Sciences/). The authors that we cited earlier, who have once again discovered the relevance of complex adaptive systems ideas to development, also implicitly point to this responsive capacity strengthening agenda. Our final message is that these parallel debates and areas of academic discourse need to be boiled down to some relatively simple and generalisable set of principles and that those interested in systems ideas in development use these principles to break down the barriers to these ideas in the dominant paradigm of development practice.

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