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Viewpoint – Water Variability, Soil Nutrient Heterogeneity and Market Volatility – Why Sub-Saharan Africa's Green Revolution Will Be Location-Specific and Knowledge-Intensive

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ABSTRACT: In his interesting *Viewpoint* article in Water Alternatives, Bruce Lankford suggests that an African Green Revolution cannot come about without irrigation. But he does not convincingly explain why irrigated areas expand only very slowly. This viewpoint article argues that grain yields have remained stagnant in Africa because of high temporal rainfall variability, significant spatial soil nutrient heterogeneity, and weak and volatile markets. This combination calls for location-specific interventions that are aimed at enhancing farmers' capacity to buffer water variations and address nutrient deficits. This finding is consistent with what Lankford dismisses as an "atomised" approach, but which would preferably be called a farmer-centred approach. Thus a massive investment in African agriculture is indeed required, primarily focused on the creation of knowledge that does justice to the local variation in water and nutrient availability. It should aim to empower farmers to experiment and be innovative, and remake agricultural extension and agricultural engineering exciting with cutting-edge disciplines. Irrigation may then emerge as the right thing to do.

KEYWORDS: irrigation, investment, food security, rainfed agriculture, policy, on-farm research, Africa

The reluctance of African farmers to adopt new practices may not be the cause of the current problems, but only an expression of the inappropriateness of the technology that is being offered because the natural conditions in Africa are truly different from those in the countries where the Green Revolution was successful.

Voortman et al., 2003

This short comment is triggered by Bruce Lankford's interesting *Viewpoint* article in the October 2009 issue of Water Alternatives (Lankford, 2009). Lankford gives some useful policy suggestions for agricultural water management in sub-Sahara Africa (SSA). I fully concur that "control of water over space and time [gives] farmers a sufficiently predictable and secure crop-growing season to invest in labour, seeds, land preparation, agrochemicals and harvesting technologies, thereby offering new crops and boosting yields by various means". In the view of Lankford, irrigation is the only viable form of water control, dismissing other types of water control, including improved use of rainwater, e.g. through soil and water conservation measures and soil moisture management, as well as through techniques that smartly combine green and blue water management, such as rainwater harvesting techniques. He boldly states: "Irrigation schemes represent a chance to potentially replicate conditions that underpin the production gains witnessed in South Asia over the last 50 years".[1] So the real

[1] This statement resonates the comprehensive agriculture development programme that NEPAD formulated in 2002. This programme envisaged to double the area under improved land and water management in Africa at a total investment cost

question he seems to address, though implicitly, is: how to replicate the Green Revolution in SSA. This is an ambitious question that requires careful thought. He suggests that such a revolution cannot come about without irrigation. This is what I question. In this opinion paper I want to provide a few thoughts on why the Green Revolution recipe has not (yet) worked in SSA, and offer some suggestions how it could.

CAN IRRIGATION KICK-START AFRICAN AGRICULTURE?

Lankford makes a case for outscaling what have been called "islands of salvation", namely those few successful irrigation schemes of SSA that have so far benefited a few private individuals at high public cost (see e.g. Hope et al., 2008). He does not explain why such outscaling has not happened by itself, but he suggests that it is because the wrong technologies have been promoted, and that irrigation development has been too expensive. To be fair, he mentions many other challenges, such as uncertain markets and the vagaries of SSA weather, but these factors are not central in explaining the low pace of irrigation development, and hence are not the starting points for trying to break the stalemate. If we get the right irrigation technology at the right cost, nothing lies in the way of an African agricultural revolution.[2] I do not think that such a strategy will remove the major constraints that can explain Africa's stagnant agriculture. Water variability, nutrient heterogeneity and market volatility are in my view more fundamental factors that can explain it, and hence lead the way to solutions. Before going into water and nutrients, first I have to briefly mention arguably the most important constraining factor.

We agricultural engineers still appear to believe that if a farmer is given irrigation equipment, economic development will follow. But unfortunately this is only true where irrigation potential positively articulates with market demands. All the places where irrigation thrives in Africa, whether self-initiated, government-initiated or company-ruled, have relatively strong and predictable output markets (see e.g. Ofosu, et al., 2009; Veldwisch, 2009).[3] In the absence of such markets, or where markets are extremely volatile and unpredictable, or where prices are kept artificially low, irrigation development beyond subsistence levels simply fails. So we should not overestimate the catalysing potential of our supply-oriented approach. There have been too many entrepreneurial African farmers who, after several years of being innovative, have been disappointed an equal number of times by merciless market gluts and have moved their innovative energies into other realms. Of course, there is both a chicken-egg question and, indeed, a dynamic relationship between demand and supply, but a steady positive trend in irrigation development is more logical than a radical expansion.

WHY HAVE GRAIN YIELDS REMAINED STAGNANT?

Grain yields have remained very low in SSA: between 0.5 to 2 tons per hectare on rain-fed plots, but not much higher on irrigated plots. There are many agronomists who argue that nutrients, not water, are the major limiting factor in agricultural production in most semiarid and subhumid areas. This position seems to be corroborated by the fact that, in SSA, soils tend to be poor while farmers, on average, apply 10 times less fertilizer than their counterparts in East, South-East and South Asia (FAO, 2008).

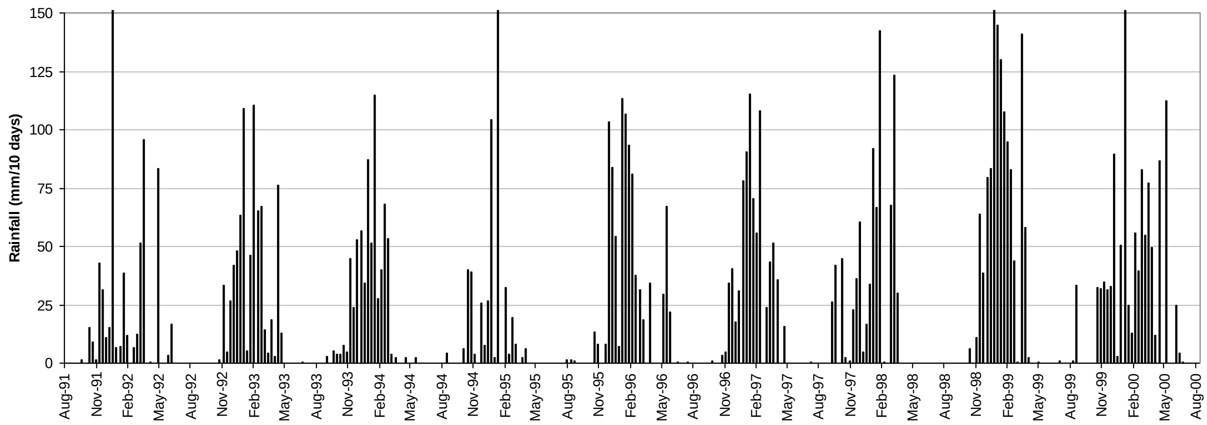
(excluding O&M) of US$37×$10^9$ (average US$1,880/ha). The investments included the rehabilitation and construction of large-scale irrigation schemes covering 5.5 million ha, as well as small-scale irrigation developments on 14.2 million ha.

[2] This strategy will require the drastic reduction of construction and/or rehabilitation costs of irrigation infrastructure from about $10,000 to less than $1,000 per hectare. It remains unclear, however, whether this cost reduction can indeed be achieved. "By sharing costs with farmers using income from cropping, and spending a higher proportion on institutional support at the system and catchment level we should meet sustainability objectives" will not take us very far, I am afraid.

[3] Note further that in many irrigation schemes in SSA most agricultural production occurs during the *rainy* season and produces typical staples for which there is a ready market, while production during the dry season, relying on full irrigation, remains low and often involves crops other than staples for which the demand is much more volatile.

The question thus becomes: why do SSA farmers apply so little fertilizer? There are two plausible explanations. The first explanation is already implicitly answered by Lankford, namely that whereas the nutrient status of a farmer's field varies slowly over time and thus can be anticipated by the farmer, water availability is highly uncertain, especially in rain-fed agriculture because of the high temporal variability of rainfall (figure 1). However, irrigators may also face large uncertainties in water availability in badly functioning irrigation schemes. Water uncertainty inhibits poor farmers to invest in the soil, and especially in fertilizer—a bad rainy season will lead to crop loss and thus of the money invested. This is a risk that poor farming households cannot simply afford to take. The solution to this phenomenon is clear: neutralise the stochastic constraint first, even though the lack of nutrients may be the largest constraint, by finding ways to enhance farmers' control over water, be it rainfall and soil moisture (green water), water in rivers and aquifers (blue water) or combinations thereof.

Figure 1. Rainfall patterns of nine consecutive rainy seasons (120 days from the first week in November until the last week of February), Harare, Zimbabwe, 1991-2000.



	1991-92	1992-93	1993-94	1994-95	1995-96	1996-97	1997-98	1998-99	1999-00
Mean	29.7	51.7	50.5	32.3	57.9	54.3	39.7	90.9	49.2
SD	50.5	37.6	28.1	48.4	48.5	41.1	41.7	56.8	42.8

Unit: mm of rainfall per 10-day period. Average annual rainfall is 840 mm/year (standard deviation [SD] is 260 mm/year). Rainfall patterns during the rainy season differ markedly from year to year, making rain-fed farming risky.

The other explanation is that the crop yield response to fertilizer use in Africa has been much lower than in Asia, and that for many farmers fertilizer use may even be uneconomic, especially those whose farms have poor soils (Kelly, 2005)! Voortman et al. (2003) explain this by pointing out that the Green Revolution successes in Asia mostly occurred in areas with extensive alluvial soils that are relatively young. The chemistry of such alluvium has a low spatial variability as well as a rich diversity of material at every location. Crops cultivated on these soils tend to respond favourably to macro-nutrient (NPK) fertilizer applications. In contrast, a large part of SSA soils are derived from a very old Precambrian Basement Complex. The old "Basement Complex implies spatial heterogeneity of in situ formed soils due to differences in the mineral assemblage of parent material". Such soils tend to have nutrient imbalances and micronutrient deficiencies, and there is a high spatial diversity in soil properties. Of course, Africa also has alluvial and volcanic soils, but these are not very extensive. The alluvial areas are mostly older than their Asian counterparts and tend to suffer from poor drainage, salinity/sodicity, chemical imbalances, etc. Voortman et al. (2003) conclude that blanket recommendations for simple macro-nutrient fertilizer use is inappropriate in such contexts and may not have the desired effects.

What makes this spatial geological perspective even more relevant is its link with groundwater. The Asian alluvial plains tend to have relatively easy access to groundwater, which makes the Green Revolution in many parts of Asia groundwater-driven. Where groundwater is easily accessible in SSA, it is often not in high demand. Where groundwater could be most productive, it tends to occur in fractured rocks, which are difficult to locate and with high drilling costs, and when groundwater is found, yields tend to be low, increasing the cost (Giordano, 2006). Moreover, soils tend to have highly varying but generally low capacities to store soil moisture in the unsaturated zone.

TRIGGERING LOCAL SOLUTIONS

A clear picture thus emerges: Africa is characterised by high temporal rainfall variability and high spatial soil nutrient heterogeneity. This combination calls for location-specific interventions that are aimed at enhancing farmers' capacity to buffer water variations and address nutrient deficits. This finding is consistent with what Lankford dismisses as an "atomised" approach, but which would preferably be called a farmer-centred approach.[4] The focus of such a farmer-centred approach would be, first, to enhance the capacity of farmers to observe site-specific biophysical and climatic phenomena, compare these with those in neighbouring fields, and in processing this information conclude which technologies and strategies can suitably drought-proof the farming system (box 1), and which organic or inorganic materials are needed and available to balance the soil nutrient status for optimal growth. The second step would be to facilitate farmers to indeed make the required investments, for example, through low-interest credits and crop insurance schemes (Hess and Syroka, 2005; World Bank, 2005).

Box 1. Farmer participation in research on smallholder system innovations (SSI) in integrated watershed management in South Africa and Tanzania.

The SSI programme (2003-2009) studied the potential of indigenous and exogenous water system innovations in smallholder farms for improved land and water productivity in two catchment areas, the Potshini catchment in South Africa and the Makanya catchment in Tanzania. These innovations ranged from in situ practices, such as deep tillage and zero tillage, to infrastructural interventions, such as underground storage tanks and small storage structures.

The programme devoted considerable effort to establish a biophysical monitoring network including a range of instrumentation on the field sites, involving local communities in participatory field monitoring and data collection. Rain gauges, river water measuring equipment and water storage systems were installed, and farmer field schools set up to enable farmers to experiment and analyse specific situations, decisions and outcomes. Indeed, the involvement of members of the local community building these water storage systems and in various monitoring activities led to the establishment of strong linkages between themselves and the SSI programme resulting in enhancing mutual knowledge and understanding of crop, land and water management issues in the study catchments.

SSI researchers have trained participating farmers on how to use the rain gauges to record rainfall events, analyse seasonal rainfall data and compare them with those in previous seasons; and finally, to confront this information with crop yields obtained and compare results with those of neighbouring farmers. Some of the more enterprising individuals are now better able to judge which combinations of new and old practices benefit their farms.

A body of knowledge and of critical reflection has thereby been, and continues to be, built up among groups of farmers, which will hopefully lead them to share and exchange experiences and select, experiment and adopt new and better farming techniques and practices. This innovative type of agricultural extension has not only enhanced farmers' capacities, but also benefited the research team: for example, the rainfall data recorded by 31 farmers in Makanya made a major contribution to assess the spatial rainfall variability in the catchment.

[4] Lankford embracing "communities of smallholders, not individual smallholders" is reminiscent of a glorification of an African community that does not exist (see e.g. Hasler, 1996).

The investments made in setting up the monitoring networks, including several permanent structures, also allow the collaborating partner institutions in the two catchments to continue using the field locations as field research laboratories and demonstration sites for farmers, researchers, extension agents, and even schoolchildren.

Sources*:* Kongo et al., 2007; Enfors et al., 2008; Sturdy et al., 2008; Makurira et al., 2009; Mul et al., 2009.

In such an approach, irrigation is not an end but a means; the end being to make farming livelihoods more resilient, and prosperous, in the face of high heterogeneity and high uncertainty. Means other than irrigation are, in particular contexts, likely to be more appropriate. Such a farmer-centred capacity development approach is currently lacking in most African agricultural extension systems, which has tended to favour simple and blanket recommendations that were based on the science of the 1960s and 1970s (see e.g. Davis, 2008).

This also has far-reaching implications for the educational system and the curricula that produce agricultural extension workers and their lecturers. It will also have implications for country-specific and locality-specific research into soil fertility, soil and water conservation techniques and practices, and irrigation technologies. Moreover, it requires the development of new modes of on-farm research experimentation with, and by, farmers. In short, the envisaged approach is knowledge-intensive (cf. Giller et al., 2009 on conservation agriculture).

THE RISKY PATH

Policymakers in Africa face a dilemma of prioritising policies that address the majority rain-fed farmers or the minority irrigation farmers. Both pathways face different short-term risk profiles. The risky path would be to prefer upgrading rain-fed agriculture: there is no precursor to such a green water revolution; there is the daunting task of reaching millions of the often uncaptured peasantry (cf. Blaikie, 1985); there will be little ribbon-cutting involved so that the political expediency may be limited, and donors and experts may not find it very challenging either. The alternative is to take the well-trodden and less-risky path where everyone involved is likely to gain, professionally, politically, and/or financially, with the exception, of course, of the majority rain-fed farmers.

Lankford dismisses rather lightly the rain-fed path to achieving food security, namely to drought-proof rain-fed agriculture, which he admits "will always constitute the bulk of agricultural systems in SSA" (about 95% of all agricultural land in SSA is rain-fed). Others have argued, however, that on-farm rain-fed crop yields can easily double or even treble, provided farmers succeed in increasing the effective use of rainfall and store more of that water to withstand dry spells (see e.g. Savenije, 1998; Rockström, 2000; Rockström and Falkenmark, 2000; Droogers et al., 2001; Rijsberman, 2004; IAC, 2004; Cooper et al., 2008; Merrey and Sally, 2006; Makurira et al., 2009; Rockström et al., 2010).

If a farm increases its capacity to store water equivalent to a water layer of 100 mm, it would be able to withstand a dry spell lasting 15 days longer than with the existing storage capacity. This additional capacity may be sufficient to withstand long dry spells that would otherwise lead to total crop failure. This is technically possible, and a suite of interventions have been suggested and are being tested in various countries including enhancing water infiltration and root development through alternative tillage techniques (see e.g. Temesgen et al., 2009), plant spacing/basins, terracing, local runoff harvesting in small underground tanks, etc. There is evidence that dry spells in certain semiarid areas in Africa are now longer and occur more frequently than in the past (Enfors and Gordon, 2007, 2008). The need for enhanced water control by farmers becomes even more urgent in the face of climate variability that are on the increase (Shongwe et al., 2009). However, this raises equity and governance issues: will this capacity to store and control water be centralised, as in the case of irrigation schemes that include many smallholder farmers and exclude those outside the scheme, or distributed, as in the case of on-farm investments in soil and water conservation measures, and local rainwater harvesting systems (Van der Zaag and Gupta, 2008)?

Many farmers find ingenious ways of combining rainfall with runoff and groundwater. It may be time the distinction between irrigated and rain-fed agriculture was done away with since there is no sharp divide. In fact, we should not underestimate what the consequences have been of such binary thinking, where irrigation is frequently equated with modernity and progress and rain-fed with backwardness. Agricultural ministries and irrigation departments need to be encouraged to collaborate. There is need to 'green' the irrigation departments and to 'blue' the agricultural ministries.

In sum, this commentary makes a case for a massive investment in African agriculture. But this investment should first and foremost focus on the creation of knowledge that does justice to the local variation in water and nutrient availability. It should aim to empower farmers to experiment and be innovative, and remake agricultural extension and agricultural engineering exciting with cutting-edge disciplines. Irrigation may then emerge as the right thing to do.

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