Addressing the yield gap in Sub-Saharan Africa

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Abstract: Increases in the production of food crops are no longer keeping pace with population growth in Africa, so the continent is increasingly relying on food imports. This would not be the case if crop yields were closer to their potential under good crop management. As climate change makes rainfall more variable, it becomes more risky for smallholders to adopt high-input technologies for crop intensification. This paper uses case studies on the yield gap in cassava, maize and cotton and examines the factors that contribute to low yields, the disincentives for technology adoption and some of the strategies required to close the yield gap. The paper argues that institutional factors are as important as technical ones in addressing the current yield gap in Africa. The main conclusions are that the yield gap is much more difficult to close in rainfed agriculture than in irrigated production where low soil fertility constrains the response to inorganic fertilizer. The combination of institutional and agronomic factors that influence the ability of farmers to improve crop yields profitably often operates at the farm or local level.

Keywords: crop production; rainfall; technology adoption; cassava; maize; cotton

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Improvements in crop yields in Africa have lagged behind those achieved in the rest of the developing world over the last two decades. Increased production has occurred through land expansion and there is a projected deficit in food production (Rakotoarisoa et al., 2011). Average yields in Africa are lower for most crops than for the same crops grown on other continents (FARA, 2009). Although the focus of this paper is on yield gaps, the context is the food and nutrition system as a whole, recognizing the importance of food quality as well as food quantity in addressing food security.

Technical innovations that would result in production surplus are rarely adopted by smallholders in the absence of market demand and market access (for example, Arias et al., 2013), so here we focus on growing crops for household income, rather than only for household consumption. However, growing crops for household food security and growing for market are not mutually exclusive livelihood strategies, and most farming households in Sub-Saharan Africa (SSA) will do both, either selling fortuitous surplus above household needs and/or deliberately planting a portion of their crop(s) for marketing.

The ‘yield gap’ refers to the difference between ‘yield potential’ and average farm yields. Yield potential is genetically determined and is the yield that could be obtained if none of the determining non-genetic factors – water availability, solar radiation, nutrients, temperature and pests and diseases – was limiting. Average yields obtained by farmers always fall below the yield potential because there is never a perfect system. In the USA, it has been estimated that under irrigated systems, crop yields are about 80% of genetic yield potential but only 50% of potential in rain-grown systems (Lobell et al., 2009). The Global Yield Gap Atlas (GYGA) is a project that seeks to quantify the yield gaps in a number of countries in SSA. The target of the project is to provide estimates of what the GYGA terms the exploitable yield gap – that is, the difference between current average farm yields and 80% of yield potential or of ‘water-limited’ yield potential (WLYP) (GYGA, 2013). Using water-limited yield is realistic, particularly for African smallholder systems (Tittosell and Giller, 2013), where irrigation is little used and crops suffer at least short-term water deficit at some point during the growing season. However, WLYP provides only very rough estimates of yield gap, and Nin-Pratt et al. (2011) have pointed out that more accurate calculation of yield gaps should be conducted over similar agro-ecological zones, which involves complex modelling. Van Itersum et al. (2013) reviewed the technical complexities of quantifying yield gap and methodological variations in yield gap assessments.
There has been a temptation to try to transfer to Africa technologies that have been perceived as successful on other continents. Two examples of this tendency are conservation agriculture and genetically modified cotton. In reality, many of the cultural, socioeconomic and institutional factors that bear on technology adoption may be country-, region- or even location-specific. With respect to crop performance, the effect of any technology on yield, as well as its likelihood of adoption, irrespective of a positive yield effect, is strongly site-specific due to complex interactions between physical and socioeconomic influences. This is well illustrated with respect to the adoption of conservation agriculture in Zimbabwe in an article by Baudron et al. (2012).

Crop case studies

In this review, three crops were chosen to examine the yield gap in more detail, although it is recognized that it can be misleading to take a single commodity perspective, as any single crop is just one component of a complex livelihood strategy for individual households, often including non-farm activity. Maize and cassava are the two most important food staples in SSA and, while maize is highly susceptible to elevated temperature and periods of drought, growing cassava is seen as an adaptive strategy for climate change. Cotton was chosen as a non-food crop as it is the predominant cash crop for smallholders in the semi-arid areas of SSA. For example, low yields from cassava may not be important if the household is food-secure and has a reasonably balanced food and nutrition strategy. Crop yields, but more importantly, production efficiency, becomes more relevant for single crops when they are being grown for income generation and being sold into commercial value chains. It is not surprising that the focus internationally is now returning to crop production, as a consequence of the current emphasis in development thinking on the commercialization of smallholder farming through improved market access and strengthening of value chains. In taking a market-led approach to rural development, it soon became apparent that high costs of production (together with poor market access, limited by inadequate infrastructure development) constituted a major barrier to profitable market participation by African smallholders (Rakotoarisoa et al., 2011).

Cassava

The average cassava yields in Africa are around 10.8 t ha\(^{-1}\), or 16% below the world average of 12.8 t ha\(^{-1}\) (FAO, 2013). Research conducted in East Africa reported average farm yields of 8.6 t ha\(^{-1}\), which increased to 20.8 t ha\(^{-1}\) under good levels of crop management (Fermont et al., 2009). Yield losses of 6.7, 5.4 and 5.0 t ha\(^{-1}\) were attributed to low soil fertility, early water stress and inadequate weed control respectively. A yield of 30 to 40 t ha\(^{-1}\) is attainable in Africa, as has been shown by well managed on-farm trials (Fermont, 2009). The yield gap is therefore around 20–30 t ha\(^{-1}\), but averages can be misleading. The figure of 10 t ha\(^{-1}\) for average smallholder yields may reflect the large amount of cassava grown extensively, much of which is intercropped. For example, smallholders in Nkhata Bay in Malawi, where average annual rainfall is over 1,500 mm, can obtain cassava yields of over 25 t ha\(^{-1}\) on their more fertile soils under sole-cropping (Hillocks, unpublished). A yield of 10 t ha\(^{-1}\) is equivalent to only 1 kg of fresh root per plant at standard spacing, which would be a very poor plant yield. Based on 80% of the water-limited yield potential (that is, 20 t ha\(^{-1}\)), there is a 46% yield gap for cassava in Africa. Using the same calculation, the global average for cassava reflects a 36% yield gap. As one estimate puts the yield gap in rain-grown crops in the USA at 50%, we must be cautious in predicting the extent to which the yield gap can be closed in African agriculture, faced with unreliable rainfall. Low rainfall or poor rainfall distribution makes it risky for smallholders to invest in high-input intensification.

More cassava is grown now in Africa than 50 years ago and it has become an important crop at all levels of smallholder farming, for both household food security and income. In one study conducted in western Kenya and eastern Uganda, Fermont (2009) found that all households grew cassava, that they were largely food self-sufficient and, regardless of the scale of the farm, that a proportion of the crop was marketed. Most households grew cassava both as an intercrop and as a sole crop, with approximately 50% of land devoted to each system. In the mid-altitude zone of East Africa, fallow periods in traditional millet/cotton and banana systems are being replaced by continuous cultivation with cassava or cassava/maize. In eastern Uganda, it was found that within 40 years, cassava cultivation had increased from 1–11% of cropped fields to 16–55% (Fermont et al., 2008). Declining soil fertility is the main driver of the switch from traditional crops to cassava, and in some places from maize to cassava (FAO, 2005).

As the commercial opportunities for cassava expand as a source of starch, in the production of biofuels or as animal feed and a source of high-quality flour for baking and other food industries, numerous value-chain projects based on cassava have been launched in Africa. Current market prices for processed cassava (typically about 70% of the price paid for similar products from wheat or maize), or for fresh cassava root, often do not provide sufficient incentive for farmers to sell their cassava, due to the high costs of production. This then creates a supply-driven or demand-driven dilemma. Projects can support production, but face the possibility of overproduction if the market is not able to absorb the surplus root, or they can support market development, which will then be constrained by a lack of raw material. Most projects implementing a value-chain approach try to do both, but in practice it is difficult to balance the proportion and timing of resources to achieve efficient production, market access and an effective value chain.

Making available high-yielding varieties is not a solution to the high cost of cassava production if the market is not assured, if the stakes are not planted at the correct spacing, if weeding is not done thoroughly enough, or if farmers are already unable to get all their crop to market due to transport or other constraints. Fertilizer application can have a large impact on cassava yields (Fermont et al., 2009), but the use of inorganic fertilizer on smallholder cassava is very rare, as the little capital that might be available is more likely to be used on maize or vegetable crops. A farmer who has only a small
amount of surplus crop for sale will naturally want the highest price per unit. The benefit of greater profit from a higher volume of sales at a lower price per unit will only be attractive if the farmer has the means to produce and deliver that higher volume to the buyer. Integrated crop management packages aimed at improving the production efficiency of smallholder cassava growing thus need to address both yield and labour savings and to cover the whole production chain, from planting through to delivery of the crop to the processor.

Maize

Maize yields in Africa, at 1.7 t ha⁻¹, are only 35% of the global average of 4.9 t ha⁻¹ (FARA, 2009). Smale et al (2011) quote averages for rain-grown maize of 1.7 t ha⁻¹ for West Africa, 1.5 t ha⁻¹ for East Africa, but only 1.1 t ha⁻¹ for southern Africa. Although maize production in Africa is increasing faster (2.8% per annum) than global production (2.5% per annum), most of the increase has come from an increase in the area cultivated rather than increased yields. Average maize yields globally are increasing faster than average yields in Africa (FARA, 2009). Figures for average yields hide a wide range of variation, and 5 t ha⁻¹ is possible in smallholder rainfed systems in SSA. Access to supplementary irrigation can raise maize yields to over 10 t ha⁻¹ (Smale et al, 2011). Based on 80% of water-limited yield potential, the estimated maize yield gap in Africa is therefore around 58%. Beyond 2025, climate change will make it more difficult to increase maize yields in some African countries (Jones and Thornton, 2003; Wheeler and Kay, 2010) due to an increase in the frequency of drought periods that exceed 10 days (see also IPCC, 2014).

Breeding for high yield in maize may be a questionable strategy when socioeconomic factors, combined with erratic rainfall, create a wide yield gap in smallholder farming systems. Breeding for high yield is the common practice in crop improvement, and it is easier than breeding for the highest possible yield under restricted water availability and low soil fertility. There are exceptions, such as the Water Efficient Maize for Africa (WEMA) project that aims to develop drought-tolerant maize varieties (AATF, 2013). Varieties selected for high yield on research stations under good agricultural practice may not out-yield local landraces unless fertilizer is applied and/or under drought conditions. This is not always the case and, for example, hybrid maize in Malawi reportedly maintained a yield advantage over local landraces, even under low fertility and drought. Adoption of hybrid maize is constrained in low-potential areas where the risk is high that the additional cost of hybrid seed, compared with open-pollinated varieties, will not be recovered (Denning et al, 2009).

There is a close association between fertilizer use on maize and good market access. Across Africa, the maize yield gap is smallest where fertilizer is used and there is strong market access. However, there are pockets where the yield gap is large despite apparently good market access, and it was concluded that this must be due to institutional and political factors constraining crop production (van Dijk et al, 2012). Apart from inadequate distribution networks for agricultural inputs, fertilizer use is still constrained mainly by cost. Sanchez (2002) estimated that one tonne of urea cost US$90 free on board (fob) in Europe, $120 delivered to the ports of Mombasa or Beira, but escalated to $500 by the time it reached western Kenya and to over $700 in Malawi.

The importance of fertilizers and policies that support their use has been well illustrated by the fertilizer subsidy in Malawi under both the ‘starter-pack’ programme during the 1990s and the government’s fertilizer subsidy that followed the 2005 famine (Denning et al, 2009). Maize yields in 2005–06 averaged 5 t/ha⁻¹ in the cluster of 11,000 farms that were evaluated, compared with 0.8 t ha⁻¹ in the drought year. Farmers in one village averaged over 6 t ha⁻¹. About 68% of the increase was attributed to a combination of improved crop management and the distribution of improved seed and fertilizer, the rest of the increase being due to sufficient and timely rainfall. The economic benefit of such input subsidy programmes has been questioned (Jayne and Rashid, 2013), and in Malawi the ability of smallholders to obtain a significant yield response to the application of inorganic fertilizer was constrained by low soil fertility and their ability to manage the crop properly (Lunduka et al, 2013). Benefits to poorer households from the low-cost fertilizer are lost due to much of it being resold for cash, rather than being used on the smallholders’ crops.

An evaluation of the Sasakawa programme to promote high-input technologies in Ethiopia and Mozambique revealed that maize yields were lowered by 200 kg ha⁻¹ for every one week of delay in planting beyond the optimum date. Yields were lowered by 280–315 kg ha⁻¹ by incorrect plant spacing, with a further decrease of 200 kg ha⁻¹ due to late weeding and a reduction of 280–315 kg ha⁻¹ caused by incorrect row or plant spacing (Howard et al, 2003). It was also noted that an economic return was not guaranteed in low-potential areas and that scaling out of successful adoption was difficult, as the expansion often encompasses areas with less favourable physical and market conditions. The evidence indicates that larger farms with medium soil fertility and good market access are those which are best able to acquire fertilizer and obtain an economic benefit. Alternatively, more integrated approaches are required for the smaller farms in less favourable areas. The use of leguminous trees on farmland, for instance, can decrease the requirement for other forms of fertilizer (Akinnifesi et al, 2010) and provide other benefits such as fodder, which can allow more of the crop residues to be retained in the field. Integration of semi-perennial legumes, such as pigeon pea, can provide a foundation for sustainable crop management, while low doses of nitrogenous fertilizer to monoculture maize have delivered significant yield gains (Snapp et al, 2010; Folberth et al, 2013).

Finally, promoting wider use of inorganic fertilizer will not on its own address the maize yield gap, especially in lower-potential areas. Where soil fertility is already poor with low organic matter content, there may be little or no response to inorganic nitrogen (for example, see Howard et al, 2003). Here, fertility remediation is required, combining conservation agriculture, where appropriate, with the use of leguminous trees, inorganic and organic fertilizers, promoted through community-based initiatives that address the livelihood system as a whole.

Cotton

Cotton is one of the most important smallholder cash crops in SSA, and contributes to food security by provid-
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ing household income for cash purchases during periods when food crops are scarce (Fortucci, 2002). Cotton differs from cassava and maize in being grown only for market, and in most African countries the majority of the crop is exported as raw lint. Another major difference is that pest control is an essential component of crop management and can account for over 50% of production costs (for example, see Vitale et al., 2011). Cotton lint yields are often quoted at around 320 kg ha\(^{-1}\) for Africa as a whole and 780 kg ha\(^{-1}\) can be achieved in research plots under irrigation in Africa have a WLYP of around 2,500 kg ha\(^{-1}\) (for example, see Gitonga et al., 2012; Kabwe and Tschirley, 2007). Cotton varieties selected in Africa have a WLYP of around 2,500 kg ha\(^{-1}\) (for example, see Gitonga et al., 2012) and yields of up to 5,000 kg ha\(^{-1}\) can be achieved in research plots under irrigation (Hillocks, unpublished). The yield gap between 80% of yield potential and the average for rainfed smallholder cotton in SSA is therefore 1,200–1,600 kg ha\(^{-1}\) of seed cotton. With the exception of South Africa, cotton is grown mainly by smallholders in SSA, and yields are typically 400–800 kg ha\(^{-1}\) for seed cotton, but some of the better cotton farmers can achieve yields in excess of 1,500 kg ha\(^{-1}\) (Gitonga et al., 2012; Kabwe and Tschirley, 2007). Cotton lint yields are often quoted at around 320 kg ha\(^{-1}\) for Africa as a whole and 780 kg ha\(^{-1}\) can be achieved in research plots under irrigation (Hillocks, unpublished). The yield gap between 80% of yield potential and the average for rainfed smallholder cotton in SSA is therefore 1,200–1,600 kg ha\(^{-1}\) of seed cotton (60% to 80%), resulting from combinations of poor crop management, low soil fertility, suboptimal rainfall distribution and pests and diseases.

Control of insect pests is particularly important for high yields in cotton, and the crop is notorious for its high dependence on pesticides. Safe, appropriate and effective application of insecticides, primarily for bollworm control, is the major problem faced by cotton smallholders. Unless close technical supervision is provided, the economic return on insecticide use is often minimal, due to poor spray scheduling, inadequately maintained application equipment, and sometimes to degraded pesticides. This has been an intractable problem and it is not surprising that GM cotton is seen as one solution to pest management in smallholder cotton (Vitale et al., 2010). In the absence of effective public extension services, the ginning companies must provide elements of vertical integration though provision of inputs and technical support. Such institutional arrangements have been the norm in African cotton, but have broken down in liberalized markets, when numerous ginning companies compete in one area, allowing farmers to access the services of one company but then sell their seed cotton to another company (Delpeuch and Vandeplas, 2013).

Early weeding and timely planting and thinning are another two requirements for high cotton yields, but shortage of labour and competing demands from food crops often mean that these tasks are delayed to the point where yield is lost. Fertilizer is also required for high yields on the sandy soils on which cotton is often grown, but there are two problems: first, fertilizer is expensive and may not be readily available; and second, gaining an economic response to nitrogen top dressing is by no means certain (see Carr, 1993). The response of a cotton crop to nitrogen is limited by rainfall distribution, low soil organic matter content, soil acidity and missing micronutrients. Furthermore, there is an interdependency between fertilizer application and insecticide application, such that obtaining an economic benefit from one requires correct application of the other. Insect pests will otherwise consume the extra crop produced by adding fertilizer, and

a crop that is growing poorly due to low fertility will not provide sufficient yield to cover the cost of a full insecticide regime. Even if the farmer is assured that his local ginning company will buy all his crop, global cotton prices fluctuate widely and may be acceptable in one year, but fall the next to a level below that which compensates the farmer sufficiently for the high labour and technical demands of cotton growing. The area of cotton planted nationally in Tanzania, for instance, can fluctuate hugely from year to year, dependent upon the price paid to the growers in the previous season (Poulton, 2009).

The key to improved yields in cotton lies in encouraging farmers to implement a fertilizer and pesticide regime correctly. Achieving a significant cost benefit from that investment then depends on three things that are within their control: (i) planting date, (ii) timely weeding, (iii) timely thinning, and one that is out of their control, (iv) rainfall distribution. Without adequate technical assistance it is almost impossible for a cotton smallholder to implement the fertilizer and insecticide regime properly. For those with the least financial capital, even the purchase of the required inputs is difficult and, if they can afford the initial investment, their ability to gain an economic benefit is often compromised by an inability to meet the labour demands for timely weeding and thinning (Bishop-Sambrook, 2003).

African smallholders are not necessarily wrong in rarely using fertilizer on their cotton. Our (unpublished) data from on-farm trials conducted in Uganda showed that out of 20 participating farmers, only four obtained a statistically significant yield advantage from nitrogen top dressing, and only one of those gained sufficient extra yield to cover more than the cost of the fertilizer. The poor response to fertilizer resulted from one or a combination of low organic matter, low pH and drought after top dressing and inadequate insect control. Cotton smallholders suffer from both ‘technical inefficiency’ and ‘allocative inefficiency’ (see Fischer et al., 2012). Technical inefficiency is mainly with respect to insecticide – the same yield could be produced by using proportionally less of it. Allocative inefficiency refers mainly to fertilizer – that is, the marginal value of applying an additional unit of input is equal to or less than the price of the input (there may be a similar outcome for some smallholders with genetically modified cotton).

The starting point in addressing the cotton yield gap is not the technology but the institutional arrangements. Some level of market protection has to be provided to ginning companies to provide the incentive for vertical integration, and they need to use that protection to deliver technical support. Contract farming arrangements can be beneficial in this respect, but require appropriate supportive policy (see Smalley, 2013). NPK fertilizer trials have been carried out over prolonged periods in several African countries, but often without providing recommendations that necessarily deliver a cost benefit (Carr, 1993). In developed country agriculture, farmers take it for granted that they base their fertilizer use on soil analysis. In precision farming, fertilizer rates are adjusted even to different parts of the field. How can it be expected that an African farmer will use fertilizer on his cotton when there is no evidence to provide guidance on which fertilizer to use and in what amounts to deliver a cost benefit, and
where vital micronutrients may be missing? Ginning companies with a guaranteed seed cotton catchment, or projects supporting cotton development, should invest in soil analysis for their farmers. Once a farmer has a guide to the fertilizer requirement and the appropriate fertilizer is available and affordable, there is still little point in applying it to the cotton crop unless the farmer is able to protect his or her additional yield from insect pests. In Uganda, scouting-based insecticide application delivers higher yields and cost benefits than calendar-based spraying (Hillocks, 2005), but it is labour-intensive and difficult for farmers to implement. A successful scouting-based integrated pest management (IPM) system also requires carefully worked-out action thresholds for all the key pests. Nevertheless, there is a compromise position in which, to encourage the build-up of natural enemies, the first spray is delayed as long as possible by, for instance, using soapy water to control early-season aphids. Regular crop inspection, without systematic scouting, can help to avoid unnecessary spraying and improve targeting. Here again, there is a role for the ginning company or projects in capacity building for farmers and extension service providers.

Labour shortage is generally a constraint to smallholder intensification and particularly to weeding (Giller et al, 2009). There are two ways to decrease the labour required for weeding. The use of animal draught power provides a quicker and more cost-effective way to manage weeds between the rows. The most efficient and cost-effective way to control weeds is by using herbicides, and this should be considered, although it will meet the objection of increased pesticide dependency. Cost and access have been significant constraints to herbicide adoption by smallholders. As pointed out by Baudron et al (2012), where land is available, the adoption of herbicides and the resulting decrease in labour requirement can sometimes provide an incentive for further extensification, rather than for intensification.

Conclusions

There is a yield gap in African agriculture characterized by low yields and both technical and ‘allocative’ inefficiencies. The average yield figures can be misleading because of the large number of near subsistence farmers and extensive production systems. The yield gap is smaller for some of the better farmers, especially where soil fertility and rainfall distribution are more favourable. The drive to increase crop yields implies intensification, but there are strong biophysical, socioeconomic and institutional factors that create disincentives for intensification. Cotton provides an example in which lack of technical capability and extension services is a major constraint to yield improvement. Unreliable markets, labour shortage and unpredictable rainfall are important factors that constrain the adoption of yield-enhancing technologies in cassava and maize. Unfavourable and unpredictable rainfall distribution is a major constraint for sustainable intensification to close the yield gap in smallholder agriculture in Africa, and it is predicted to become worse under climate change scenarios. Inorganic fertilizers are used only by a minority of African smallholders due to their expense and a scarcity of input suppliers. The approaches to creating incentives for wider adoption of inorganic fertilizer will include combinations of improved market access, transport links, improved input distribution networks, use of conservation farming methods, integration with organic manure and the use of fertilizer trees.

It is apparent that an exclusive focus on technical solutions will not address the yield gap challenge in Africa. Integrated crop management packages will need to be more widely adopted and successfully implemented, but only where the institutional and policy environment is conducive and where technologies are promoted to address the whole production to market chain, covering crop management, labour shortage and market access, including transport for the delivery of produce to the processor.

References


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