New sorghum and millet cultivar introduction in Sub-Saharan Africa: impacts and research agenda

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Abstract

In spite of substantial introduction of new sorghum and millet cultivars in semiarid Sub-Saharan Africa, there has been minimum aggregate impact on yields (FAO and ICRISAT, 1996: The World Sorghum Economies: Facts, Trends and Outlook. FAO, Rome, Italy and ICRISAT, Andhra Pradesh, India) in contrast with other crops, such as cotton and maize. Only where inorganic fertilizers and improved water retention or irrigation were combined with new cultivars were there large yield increases. Given the low soil fertility and irregular rainfall in semiarid regions, both increased water availability and higher levels of principal nutrients apparently will be necessary for substantial yield increase. The cultivar-alone strategy is unlikely to have a significant sustainable yield effect and therefore reduce poverty in semiarid Sub-Saharan Africa.

Keywords: Sub-Saharan Africa; Sorghum and millet; Impact; Aggregate yields; Inorganic fertilizers

1. Introduction

Poverty alleviation has been a principal objective of technology development strategies in Sub-Saharan Africa for crops with drought resistance, specifically sorghum, millet, peanuts, and cowpeas. Poverty is concentrated in rural areas and a high proportion of the population (25%) of Sub-Saharan Africa lives in semiarid regions (Sanders et al., 1996, p. xix). In 1990, 48% (218 million people) of the population of Sub-Saharan Africa were living in poverty (World Bank, 1992, p. 30). Sorghum and millet contribute to the food security of many of the world’s poorest, most food-insecure,
agroecological zones (FAO and ICRISAT, 1996). These crops are also a principal staple food in the urban areas of many of the poorest countries in Sub-Saharan Africa.

The major emphasis of technological change in the semiarid region over the last three decades has been new cultivars. Our objective is to evaluate the success of new cultivar strategies for seven case studies of new cultivar introduction of sorghum and millet in Sub-Saharan Africa and then to suggest an alternative strategy to improve the productivity gains of the introduced cultivars. The first question is: have new cultivars been introduced and, if so, what are the effects of the new cultivars and associated technologies on aggregate yield levels? In the next section we respond to these questions, drawing upon our field studies in various countries. Next we dichotomize the new production systems into those that have had a noticeable aggregate impact on yields and those that have not. Then we consider the components of the successful technology components observed. In the conclusions we offer some implications for policies and markets.

2. New cultivar introduction in semiarid Sub-Saharan Africa

Farming in drought areas has been characterized as a subsistence activity with farmers producing a wide array of crops (including multiple cultivars of the same crop) for their own consumption, using few purchased inputs. With low expected profitability of crop production, it is a rational strategy for farmers to retreat toward subsistence (as farmers did in the Great Depression), market little, purchase few inputs, and produce more for their own consumption (Paarlberg, 1988, p. 8). Given the climatic and price variation, poor soils, insect and disease problems, agriculture is risky in semiarid regions. Rather than focusing on profitability and risk reduction in agriculture, public policy has been to search for technologies involving minimal expenditures by farmers and no foreign exchange. Hence, the emphasis in new technology introduction has been on new cultivars and increased utilization of on-farm and within-region resources to minimize cash expenditures.

Despite lagging behind many other commodity-based research programs, such as maize and cotton, sorghum and pearl millet research in Sub-Saharan Africa has been successful in diffusing a large number of new cultivars onto farmers’ fields. The last two decades of research have resulted in the release of over 40 sorghum cultivars in 23 countries and 16 millet cultivars in 12 countries (Miller et al., 1996; Rohrbach, 1996).

Among the large number of new cultivars, we studied seven success stories of diffusion (Table 1). Outside of South Africa and Sudan, most of the new cultivars are open-pollinated and early maturing. Thus, drought escape was a principal factor in the breeders’ strategy to overcome the moisture constraint in the semiarid environments. During the last 30 years in the Sahel, rainfall has been one standard deviation below the long-term normal (Fig. 1). In southern Africa, there were several major droughts in the 1980s and 1990s.

Since there were substantial drought problems in the 1980s, the earliness of these cultivars has been much appreciated. However, short-seasoned cultivars are generally adopted by farmers as part of a portfolio with other longer-season cultivars to take advantage of the years when rainfall is adequate or good.
Earliness gives drought escape but reduces the potential of the plant to respond to better growing conditions since the plant will not be in the field long enough to take advantage of these conditions (Shapiro et al., 1993). An example of the disadvantage of earliness is the S-35 cultivar. S-35 was selected from ICRISAT material in northern Nigeria and then made available in regional trials to Cameroon. In 1984, widespread trials on farmers’ fields were implemented. In this major drought year, the yields of the early S-35 doubled the local and other new cultivar yields (Johnson, 1987, p. 657; Kamuanga and Fobasso, 1992, p. 22). There was no yield advantage to S-35 in normal and good rainfall years after 1984. For a portfolio addition to protect against dry years, S-35 was very popular. After its release in 1986, farmers in northern Cameroon began rapidly introducing S-35 into their mix of cultivars of different season lengths. Nevertheless, since S-35 was only one of a number of cultivars grown by individual farmers and yield effects were small except in poor rainfall years, the rate of return was very low, only 2%, a marginal investment. Thus, we would expect only small-scale or partial adoption of early maturing cultivars and lower rates of return than would be expected with normal or late-maturing cultivars accompanied with higher input levels (Table 1). So there is a cost to drought-escape strategies.

Table 1
Selected characteristics of the successful new sorghum and millet cultivar introductions

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Country</th>
<th>Year of release</th>
<th>Season length</th>
<th>Current adoption</th>
<th>Internal rate of return</th>
<th>Change in input use</th>
</tr>
</thead>
<tbody>
<tr>
<td>HD-1 (S)</td>
<td>Sudan</td>
<td>1983</td>
<td>Medium</td>
<td>17% (1993)</td>
<td>36% (low fertilization)</td>
<td>Fertilization (irrigated area)</td>
</tr>
<tr>
<td>S-35 (S)</td>
<td>Cameroon</td>
<td>1986</td>
<td>Short</td>
<td>33% (1996)</td>
<td>2%</td>
<td>No change observed</td>
</tr>
<tr>
<td>S-35 (S)</td>
<td>Chad</td>
<td>1989</td>
<td>Short</td>
<td>27% (1996)</td>
<td>12%</td>
<td>No change observed</td>
</tr>
<tr>
<td>SV-2 (S)</td>
<td>Zimbabwe</td>
<td>1987</td>
<td>Short</td>
<td>36% (1995)</td>
<td>18%</td>
<td>No change observed</td>
</tr>
<tr>
<td>Zambian cultivars (S)</td>
<td>Zambia</td>
<td>1987–93</td>
<td>Short, medium, and long</td>
<td>35% (1996)</td>
<td>12%</td>
<td>Fertilized only on large farms</td>
</tr>
<tr>
<td>PMV-2 (M)</td>
<td>Zimbabwe</td>
<td>1991</td>
<td>Short</td>
<td>26% (1995)</td>
<td>31%</td>
<td>No change reported</td>
</tr>
<tr>
<td>Okashana-1 (M)</td>
<td>Namibia</td>
<td>1990</td>
<td>Short</td>
<td>35% (1993)</td>
<td>13%</td>
<td>No change reported</td>
</tr>
<tr>
<td>NK-283 (S)</td>
<td>South Africa</td>
<td>Unknown</td>
<td>Medium to long</td>
<td>50–70% (1998)</td>
<td>NA</td>
<td>Fertilization and water retention</td>
</tr>
</tbody>
</table>

* Sources: Ahmed and Sanders, 1992; Sanders et al., 1994; Anandajayasekeram et al., 1995; Ahmed, 1996; Chisi et al., 1997; Yapi et al., 1997.
* Sorghum and millet, respectively, are identified by the letters S and M in parentheses.
* Latest available information with the year in parentheses.
* Include two hybrids and three open-pollinated cultivars of which Kuyuma and Sima (released in 1989) and MMSH-928 (released in 1993) are the most widely adopted.
Field surveys in several countries indicated that diffusion of these improved sorghum and millet cultivars is delayed by the slow evolution of the seed industry. The lack of sufficient high-quality seeds was cited as the major constraint to adoption of improved cultivars by 60, 66, and 45% of the non-adopters of PMV-2, SV-2, and the new sorghum cultivars in Zambia, respectively. In Sudan, the public sector seed producers were unable to respond to the rapidly increasing demand for HD-1 seeds (Ahmed and Sanders, 1992). In the early 1990s, approximately one-third of Gezira farmers complained about their inability to obtain HD-1 seeds and/or inorganic fertilizers and cited this lack of availability as a principal determinant of their inability to introduce the new sorghum hybrid (Nichola, 1994).

In southern Africa, the private sector has shown little interest in selling open-pollinated varieties to small-scale farmers. If farmers depend upon non-governmental organization (NGO) and government handouts of seeds, the development of private marketing institutions will be hindered unless sufficiently high prices are charged for the private sector to be interested in entering the market. Private seed and other input markets are well established in South Africa, and the private seed sector is reentering the production of hybrid sorghum seeds in the Sudan. Outside of South Africa in the other six cases, government programs played an important role in promoting new sorghum and millet cultivars, including providing the seed and often other inputs.

3. Patterns of technology adoption

Sorghum area in Sub-Saharan Africa reached a record high of over 23 million hectares in 1997 (Fig. 2) with production increasing at 2.9% annually and millet
production increasing even faster at 3.3%. Unfortunately, these gains were based upon continuing area expansion while yields continued to decline at 0.8. and 0.7 rates for sorghum and millet, respectively, for the period 1980–96 (FAO, 1998). During the past two decades with increasing population pressure on the land, the fallow-system method of restoring soil fertility has been disappearing. With declining soil fertility in traditional crop production regions, sorghum and millet have been pushed into more marginal crop areas. Due to the riskiness of fertilizer response in marginal rainfall regions and the failure of government policy to support crop productivity increase in the traditional production zones, there has been little substitution of higher input use for the soil-fertility depletion. So these gains in aggregate production are not sustainable given the continuing decline of land productivity.

In all seven cases of new cultivar diffusion evaluated, there were farm-level yield gains. However, only in the two cases of sorghum in the Sudan and South Africa are aggregate yield increases clearly visible (Figs. 3 and 4). Fig. 3 compares sorghum yields on the main irrigation project of the Gezira (approximately 50% of the irrigated area in Sudan is in this scheme) with those in the mechanized drylands, the main sorghum production area the Sudan. From 1985–1996, irrigated yields increased by 3%, whereas on the mechanized drylands they declined by 0.3% per year. The yield increases in the Gezira resulted from a combination of a high-yielding cultivar (Hageen Dura-1), fertilization, and improved agronomic practices (Ahmed and Sanders, 1992).

On the mechanized vertisols of Sudan, sorghum is produced extensively without fertilization or water-retention technologies, but new cultivars are widely adopted. Many new sorghum cultivars were introduced in the early 1970s as combinable, high-yielding cultivars (e.g. Dabar-1 and Gadam Elhamam-47; see Nichola and Sanders, 1996). In the 1990s, three new cultivars were introduced (SRN-39, IS-9830 and M-90393) with some diffusion being reported (Rohrbach, 1996). Even with these new cultivars, there were no aggregate yield effects on the mechanized vertisols.
Sorghum production in South Africa is another example where high-yielding hybrids were combined with inorganic fertilizers and water-retention technologies. On the sandy soils of the semiarid regions of South Africa, sorghum producers increase water storage in the soil by controlling weeds in the off season and cultivating to absorb more water. A sub-surface crust of 1–2 m in depth holds the water and makes it accessible to the crop. With the utilization of this water-conservation technique, the South Africans then do not need to select for earliness for drought escape. Rather, they combine a medium- to long-season-length cultivar with moderate to high levels of fertilization and attain yields of up to 7 Mt/ha.

Sorghum yields averaged 1.8 t/ha in South Africa since 1980 despite the six drought years after 1980 and the 1991–92 drought. This contrasts with the 0.8 t/ha
in the rest of Sub-Saharan Africa (FAO, 1998). Sorghum yields in South Africa show substantial variation with weather but they are substantially higher than those of the other three countries illustrated where there was also rapid introduction of new sorghum cultivars (Fig. 4).

The success of the intensive production pattern of sorghum in Sudan and South Africa is similar to the success of cotton in Francophone Africa and maize technologies in the Sudano-Guinean zone of the Sahel (Sanders et al., 1996; pp. 54–58). In these higher-rainfall regions, new cultivar introductions were combined with crop-management improvements, including increases in fertilization, density, and pest control. This maize technology introduction has resulted in rapid increases in maize yields of 1.2–4.9% annual growth rates in Mali, Ghana, and Burkina Faso. Similarly, over 60% of the threefold increases of sorghum yields in the US in 30 years were due to improved agronomy practices, especially fertilization, herbicides, and water control (Miller and Kebede, 1984, pp. 6, 11).

Sorghum and pearl millet production in Sub-Saharan Africa follows two distinct paths: intensive and extensive. The observed intensive development path utilizes hybrids and inorganic fertilizers under irrigation or with water-harvesting technology. This system characterizes sorghum production in the irrigated Gezira of Sudan and semiarid rain-fed regions of South Africa. The extensive system uses a mixture of traditional and improved, early maturing cultivars. New cultivars were generally adopted as a risk-avoidance strategy without improved agronomy. Neither fertilization nor water-retention technologies were practiced. This system dominates the small-scale farming that produces most of the sorghum and pearl millet in Sub-Saharan Africa. As a result, yields were low and sometimes declined even in countries where rapid diffusion of new cultivars was reported (Table 1; Fig. 4).

Our principal explanation for the limited aggregate gains for sorghum and millet is the over-reliance on a cultivar-alone strategy in the harsh environments where sorghum and millet are produced. In these agroecological zones, both water stress and inadequate soil fertility are generally encountered.

In Sub-Saharan Africa there are widespread soil-nutrient deficiencies. The soil-fertility situation is getting worse as increasing population pressure on the land reduces effectiveness of the fallow system or eliminates this practice. In these nutrient-stressed environments, new cultivars and low external inputs can support no more than low-productivity, subsistence type of agriculture (Crosson and Anderson, 1994, p. 16). Nevertheless, many new cultivars have been released recently and large future impacts are possible if complementary technologies are introduced.

Is there evidence for the yield and profit-increasing effects of fertilization on semiarid soils? In Burkina Faso on heavier soils there was extensive testing over 2 years in four regions, indicating that the combination of a water-retention technology and moderate inorganic fertilization increased yields by 50–100% (Sanders et al., 1996, p. 78). On lighter soils with higher levels of sand, the crusting or runoff problem is less severe, but rapid infiltration of water often results in water becoming unavailable to the plant. Here fertilization and higher densities have been shown to increase water-use efficiency by apparently increasing the water-holding capacity of
these sandy soils (ICRISAT, 1987, 1988; Mokwunye and Hammond, 1992, pp. 131, 132). Reviewing the fertilization issue on sorghum and millet, Shapiro and Sanders (1998, pp. 475, 478) showed the profitability on both heavy (with the water-retention technology of tied ridges) and light soils. The combination of inorganic and organic fertilizers on millet and sorghum were shown to substantially outyield individual use of either in a recent review (Bekunda et al., 1997, p. 66). Organic fertilizers are apparently an excellent water-retention device in both sandy and heavier soils.

4. Input and product markets

Higher input use to simultaneously overcome soil nutrients and moisture constraints is necessary to obtain significant yield effects from new cultivars of sorghum and millet. There is much discussion of substituting for soluble inorganic fertilizers with organic fertilizers, rotations, rock phosphate, and several other more exotic or region-specific alternatives. However, cereal yields have nowhere been substantially increased without moderate levels of inorganic fertilizers. These other soil-fertility measures need to be thought of as complements to, rather than substitutes for, inorganic fertilizers (Quiñones et al., 1997). It is unlikely that Sub-Saharan Africa will make scientific breakthroughs in soil fertility or change the basic economics of these would-be substitutes.

As the risk of income losses is expected to be an important determinant of adoption of inorganic fertilizers in semiarid regions, increased water availability is critical to reduce such risks. The combined technology of inorganic fertilizers, water-retention techniques (or irrigation), and new cultivars is expected to substantially increase yields and improve farmers’ incomes and nutrition. Organic fertilizers will frequently need to complement the inorganic ones to improve the retention of water and nutrients in the soil. Once soil moisture and nutrients are available, breeding strategies can emphasize medium to late-maturing cultivars to respond to the improved agronomic environment.

If sorghum and millet are not sufficiently profitable because markets do not expand or governments continue to provide poor policy support, farmers will either not use inputs or will use them on smaller areas with sorghum and millet. In this case, regional and international research priorities will need to shift from the traditional cereals since adoption of cultivars alone is insufficient to improve yields. A poverty-alleviation policy of introducing cultivars alone or with some soil-fertility measures but without inorganic fertilizer will not be sustainable as soil nutrient mining continues.

The major emerging constraint, once the diffusion process of new cultivars and associated technologies has begun, is the ability of input markets (seeds, fertilizer, and credit) to respond to rapidly increasing demands. Policy measures that reduce the prices paid by farmers for the inputs used or increase the prices received by farmers for the resulting outputs will strengthen farmer incentives to adopt these innovations. Public investment in marketing and transportation infrastructure would reduce input costs and increase producer prices by reducing transaction costs.

Attention to the evolution of new uses in the product markets should also accelerate diffusion by moderating the between-season price collapses and partially
offsetting the long-run price decline resulting from successful technology introduction. Market development, as for the use of domestic cereals in bread and beer, can serve an intermediate function until domestic incomes rise sufficiently to begin the rapid dietary change to animal products and therefore the shift to the rapidly accelerating use of cereals as feed, as has already occurred in many developing countries.

5. Conclusions

Everywhere in the world that yields have been successfully increased in semiarid regions, including Sub-Saharan Africa, more water and inorganic fertilizers have been required. The breeding effort with sorghum and millet has been outstanding and needs to continue, but things need to be made easier for the breeders with an emphasis on improving the production environment and increasing the profitability of traditional cereal production. Short-term yield increases that are not sustainable due to increasing soil-fertility deficits will not have long-term effects on poverty reduction.

During the last two decades, increases in sorghum and millet output in Sub-Saharan Africa to feed the growing population were possible only through rapid area expansion because yields were low and declining. In the long run, the current area expansion can be reversed by successful implementation of the combined technology. Over time, as the benefits of combining moderate levels of inorganic fertilizers, water retention, and improved cultivars become apparent, farmers will gradually increase the level of input use by reinvesting part of the additional gains. The increased production of these traditional staples can be absorbed by new markets, especially the use of feed grains for poultry and milk production as the demand for animal products accelerates with economic growth.

An important issue for this region is whether low-input strategies have been prompted by the poor resource base and riskiness of these agricultural systems or by the over-emphasis in public policy on maintaining low food prices to the detriment of the modernization process in agriculture. To transform the agricultural sector in semiarid regions, farming needs to be profitable and risk reduction feasible, thereby encouraging farmers to purchase more inputs and increase land productivity. Technical options are available but farmers need a profitable environment. An over-emphasis by policymakers on maintaining low urban food prices can make the shift to more intensive production practices less likely. So technical, economic, and public policy support need to be combined for increasing productivity and incomes in semiarid regions.

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