9-9-2013

Economic Impact Assessment of Sorghum, Millet and Other Grains CRSP: Sorghum and Millet Germplasm Development Research

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Kansas State Research and Extension Contribution Number: 12-192-D

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Executive Summary

Project rational

1. In general, impact assessment studies are used to aid for designing and planning of future projects and accountability of past investments. In 2008, INTSORMIL received four year funding at $1,250,000 per year (2008-2009 to 2011-2012) to expand all activities and to develop institutional capacity by adding a degree and short term training component to the Cooperative Agreement (INTSORMIL, 2009). One of the initiatives suggested by USAID was impact assessment studies of each of the four regional programs: Central America, East Africa, West Africa and Southern Africa.

Sorghum and Millet Production and Trade Patterns

2. During INTSORMIL's lifespan, Nigeria, Niger, Mali, Senegal, Ghana, Burkina Faso, Ethiopia and Uganda have seen an increase in the area harvested (ha) to Sorghum. On the other hand, the area harvested (ha) to sorghum has dwindled in South Africa and Botswana. There was no remarkable change for Zambia, Nicaragua, Honduras, El Salvador, Kenya, Zimbabwe, and Mozambique. Countries which allocated increasing part of their arable land to Millet were: Niger, Nigeria, Mali, Burkina Faso, Uganda, Ethiopia, and Zambia.

3. In general, the total world area (ha) allocated to sorghum production has been in a declining trend. However, the yield productivity (kg/ha) has been slowly rising overtime. As a result of the offsetting effect of a rise in productivity, the world sorghum production (tonnes) has been on a rather constant/horizontal trend. The world area allocated (ha) for millet has been declining significantly over the last two decades. On the other hand, millet yield productivity (kg/ha) has been improving with increasing trend. As a result, the overall world millet production (tonnes) has been following an upward trend.

4. There appears no visible sorghum export share to the total world trade coming from INTSORMIL host countries. There had been sizable millet exports from the West African region as much as 10% in the mid 1980s but has since been in a declining trend (less than 2%). The percentage share of world millet imports by the East African region has remarkably increased over this period (more than 10%). This figure for the West African region has been fluctuating a great deal but with a horizontal trend. However, this region had as much as 30% share of the world millet trade around the year 2000. In 2008, the leading sorghum exporters were the United States and Argentina and the leading importers were Spain, Mexico, and Japan. For millet, the leading importers were Yemen, Belgium and United Arab Emirates and the leading exporters were India, distantly followed by United States of America and Ukraine.

5. Sorghum is a major cereal and food source for sub Saharan Africa and India. Two out of the top 5 highest sorghum producing countries in the world are from Sub-Saharan Africa and thee out of the top 5 highest millet producing countries in the world are from Sub-Saharan Africa. In 2008, according to FAO data estimates, the United States was the leading sorghum producer in the world followed by Nigeria, India and Sudan.

6. INTSORMIL and ICRISAT are the two major international organizations working in collaboration with host countries' National Agricultural Research Systems (NARS) , Universities, private organizations , and others in developing new technologies to improve sorghum, pearl millet and other grains production and utilization worldwide.

Background on Sorghum and Millet Improvement through INTSORMIL

7. The improvement programs/strategies through breeding under the mandate of INTSORMIL include: *Germplasm Collection and Conservation, Conversion, Hybrid Production, Population Improvement, Breeding for Abiotic Stress, Breeding for Biotic Factors, and Grain Quality Improvement*. Currently there are 15 active global projects under INTSORMIL's management. One in three of these projects is involved in breeding and varietal development. One out of four of the INTSORMIL trained (1979-2009) individuals have obtained training on breeding and varietal development.

8. During the last three decades, there have been huge numbers of breeding lines, parental stocks, germplasm and cultivars released through INTSORMIL/host countries collaboration around the world. INTSORMIL reports reveal that there have been remarkable breeding success stories such as the release of the first hybrid sorghum Hageen Dura (HD-1) and *Striga* tolerant varieties in Sudan; the introduction and release of Sureno sorghum variety in Honduras ; and numerous other releases in various other African and Latin American countries such as Mali (Malisor lines with excellent head bug resistance, N'Tenimissa-tan plant guinea type cultivars), Niger (high yielding varieties as well as drought resistant hybrids), Nigeria (LCICMH-I -a pearl millet hybrid with early maturing characteristic), Zambia (improved varieties such as Kuyuma and Sima and hybrids such as MMSH-928 for drought prone areas , MMSH-1324 for resistant to most diseases, and MMSH-1256 widely adapted to most of the country) and Ethiopia (Striga resistant varieties such as Gubiye, Abshir and Brhan), Columbia (two varieties, Sorgo Real 40 and Sorgo Real 60 that are tolerant to Al and salt). In addition, INTSORMIL reports show that germplasm lines have been developed and released to the private industry and elsewhere. For example, From 1979-1993, a total of 415 germplasm lines, populations, parental lines, and converted exotic lines have been released. During 1997-98, 62 parental lines of sorghum and 7 of grain pearl millet were released by the Nebraska INTSORMIL collaborating breeder (INTSORMIL annual report, 1998). By late 2000, since the inception of the INTSORMIL program, the total released fully converted lines were 700 (INTSORMIL annual report, 2000).

Global Impact of Sorghum and Millet Improvement Strategies

9. Although impact assessment refers to a broad range of issues, for the current study it is specifically confined to economic impact assessment because of the availability of data that is mostly suitable to undertake such analysis, and because of the limitations of the project funds and time. The internal rate of return (ROR) is the most popular metric used to measure the return on investment on agricultural research and development.

10. Alston et al. (2000) broadly categorized the factors that account for variation in measured returns to agricultural R&D were to: 1) Characteristics of the rate of return measures , 2) Characteristics of the analysts performing the evaluation , 3) Characteristics of the research being evaluated , and 4) Features of the evaluation . For the current study, over all there were 22 publications reviewed and 49 observations collected for the internal Rate of Return (ROR) studies (there were additional adoption studies as well).

11. A large majority of the studies were ex-post type of analyses (68 % for both publications and point estimates), indicating that most of these studies on sorghum and millet were conducted to evaluate the consequences of past R&D investments. For the sub-Saharan Africa countries for example, all except one study were an ex-post type of analyses. Most of the studies (86% of the publications and 74% of the point estimates) computed an average RORs compared to marginal RORs. This is due to widespread use of the economic surplus method to calculate the benefits of R&D to society. In addition, all of the studies reviewed, calculated social (as opposed to private) rate of returns (Table 1). This is particularly true in the case of the studies reviewed involving the sub-Saharan Africa case studies, because all of the technologies developed originated through the use of public funds in the host country National Agricultural Research Systems (NARS) and from international partners such as ICRISAT , INTSORMIL, and collaborating institutions.

12. Sorghum and millet grow in very harsh environments where other crops do not grow easily. In general, due to these production and peculiar consumption characteristics of sorghum and millet around the world, the ROR studies seem to be concentrated in certain geographic areas of the world. Millions of the poorest people in the semi-arid tropics of Africa and Asia consume sorghum and millets. More than half of the impact assessment studies (64% of the publications) were conducted in the Sub-Saharan Africa, followed by almost a quarter of the studies being in the United States (23%) and India (4.5%) (Table 2).

13. More than half of the studies (59 % of the publications) reported the two major sorghum and millet improvement organizations around the world - the INTSORMIL and ICRISAT -as the primary source of the technology (e.g. breeding materials to develop the sorghum and millet technologies). This is followed by other categories (32% of the publications) such as private organizations and universities that are not directly affiliated to these two institutions (Table 3).

14. Although both Sorghum and millet are included in the review of studies, close to three quarter of the studies focused only on sorghum (73% of the publications) and one tenths of the studies (9% of the publications) dealt only with millet (Table 4). This comes in no surprise because of the economic importance and wider usage of sorghum in the countries where the studies were conducted and the relatively higher investment expenses by research institutions on sorghum than on millet.

15. The distribution of the rates of returns to sorghum and millet appears to have a bimodal distribution (Figure 1). The average ROR for this set of data was 84.71 and around 10 % of the studies have an ROR of less than 10% and 16 % of the studies have an ROR of less than 15%.Two publications (4 point estimates) have reported an ROR of more than 300 percent. These two studies were conducted in the United States and the very high rates of returns may be due to the better technology packages available in the United States that makes the adoption and diffusion of the technologies much easier compared to other less developed countries where the adoption and diffusion of the new technologies are hampered

by many critical factors. The distribution of the rates of returns excluding these two publications is shown in Figure 2. The average ROR for this set of data is 59.17 and around 11 % of the studies have an ROR of less than 10% and 18 % of the studies have an ROR of less than 15%. There is high dispersion of the observations around the mean for the data set in Figure 1 with standard deviation of 94.54 compared to the data set in Figure 2 with a much smaller standard deviation of 38.91.

16. A Meta-analyses of the returns to research was done to find some explanation for the variation in rates of return to agricultural R&D using the entire case studies on sorghum and millet. The dependent variable was the Rate of Return to Agricultural R&D measured in percentage (%) term, which is a continuous variable. We seek to explain the variation in the RORs using variables using the four broad categories of explanatory variables described earlier.

17. *Higher* rates of return are indicated when the rate of return is:

- Ex ante (versus ex post), in contrast with the Alston et al. findings statistically significant at 90% confidence level
- the research evaluation is a self-evaluation (rather than an independent evaluation) in contrast to the Alston et al. findings, however this variable is not statistically significant
- Pivotal supply shift (versus parallel or other supply shift assumptions) in agreement with Alston et al. findings , although this variable is not statistically significant

Lower rates of return are indicated when:

- the evaluation is published in a refereed journal compared with less formal outlets , in agreement to the Alston et al. findings, although this variable is not statistically significant
- when the evaluation exercise is conducted by an international institution (as opposed to University), statistically significant with 95% confidence level
- when the evaluation exercise is conducted by a mixed institution (as opposed to University) with 95% confidence level
- if the scope of research evaluation conducted is at a multinational scope (versus sub national scope), however this variable is not statistically significant
- if the scope of research evaluation conducted is at a national scope (versus sub national scope) , with a 95% significance level.

18. Excluding the variables that are not statistically significant, we may interpret the constant coefficient as an ex-post research evaluation conducted at a sub-national level (certain area or region within a country/nation) by a University research evaluator will have an average rate of return of 126%. We may also conclude that all else kept constant, impact assessment conducted at a national level produce lower rates of return (ROR). Evaluations conducted by a team from both mixed institutions and international institutions have yielded lower rates of return compared to University evaluators, all else kept constant.

19. Controlling for the type of commodity analyses, the meta-analysis for returns to research were analyzed for sorghum only. There were not enough observations to conduct similar analyses for Millet studies only. An unpublished independent (as opposed to self assessment) ex-post evaluation conducted by a university evaluator on average had an annual rate of return of 76%. Keeping everything else constant, the rates of return are lower for studies that were published. Compared to University, mixed institution evaluators had lower rates of return as well. However, both ex-ante and self evaluated studies showed higher rates of return, all other variables kept unchanged.

Conclusion and Recommendations

20. As a result of the offsetting effect of a rise in productivity and decline in harvested area, the world sorghum production (tonnes) has been on a constant/horizontal trend. The combined effect of a decline in area harvested and a rise in yield productivity have resulted in an overall increase in world millet production (tonnes) trend.

21. Currently there are 15 active global projects under INTSORMIL's management. One in three of these projects are involved in breeding and varietal development. Breeding strategies/programs through INTSORMIL integrate: *Germplasm Collection and Conservation, Conversion, Hybrid Production, Population Improvement, Breeding for Abiotic Stress, Breeding for Biotic Factors, and Grain Quality Improvement*.

22. On a global coverage, the average rate of return to sorghum and millet agricultural R&D investments is about 60 percent per year which is in the range of the average rate of return estimated for agricultural R&D investments. Despite the positive and promising returns to investment in sorghum and millet researches, there appears to be limited economic analysis done in such endeavors. It is important to increase the impact assessment studies to provide empirical support to investments in sorghum and millet improvement technologies.

23. INTSORMIL host countries have benefited from a significant amount of cultivar releases over the last three decades. Based on INTSORMIL reports and successful releases as well as potential adoptions, more impact assessment type of studies should be done in general in Asia (India) and the United States as well. Other countries for that deserve economic impact assessment are: Honduras (for example the variety Sureno), Columbia (aluminum/salt tolerant varieties), Mali, Niger and Zambia (all with multiple cultivars) particularly based on the significant amount of varietal releases in record during the life span of INTSORMIL. Analysis of dynamics of the data on the area harvested during INTSORMIL's lifespan would also show that Nigeria, Niger- for example SEPON82 is the most adapted cultivar in Southern Maradi region of Niger[1] -, Mali, Senegal, Ghana, Burkina Faso, Ethiopia and Uganda have seen an increase in the area harvested (ha) to Sorghum that lends support to the need to undertake impact assessment studies.

24. So many reports reveal that quite significant amount of releases are already out there for farmers to use. In spite of the successful research and development progress shown through INTSORMIL in particular and local and international research centers in general, nonetheless, the lack of functional

[1] http://intsormil.org/SMNewsletterArchive/2011AugustINTSORMIL_Newsletter.pdf

technology transfer institutions continue to pose significant impediments for the overall solutions to development in agriculture.

25. In general, it is observed that the majority of the economic impact assessment studies were evaluations of past R&D investments (ex-post type analyses) and even more so in the Sub-Saharan Africa countries. Even though, the amount of such ex-post studies is by no means enough, it is essential to consider that adequate economic impact assessment studies (ex-ante type) be undertaken to help aid in the crafting of effective technology introductions and policy designs in the future.

Economic Impact Assessment of Sorghum, Millet and Other Grains CRSP: Sorghum and Millet Germplasm Development Research

Rational and objective for the impact study

Agricultural research organizations are under continual pressure to conduct impact assessment of their research activities and to better integrate the social, economic and environmental considerations in research planning and implementation. Impact assessment is done for several practical reasons: (1) *Accountability* – to provide empirical evidence of the effectiveness of past investment for driving outcomes of interest and validate the relevance of overall strategies pursued ; (2) *Improving program design and implementation* - to learn lessons from past that can be applied in improving efficiency of research programs; and (3) *Planning and prioritizing* - to assess likely future impacts of institutional actions and investment of resources, with results being used in resource allocation and prioritizing future programs and activities, and designing policies, programs and projects (TAC Secretariat, 2000). In 2009 the INTSORMIL authorization ceiling for the period September 30, 2006 to September 29, 2011 was increased from $9,000,000 to $12,900,000. One of the initiatives recommended by USAID was impact assessment studies of each of the four INTSORMIL regional programs; Central America, East Africa, West Africa and Southern Africa.

This review documents INTSORMIL's sorghum and millet varietal improvement research achievements accomplished so far and assesses the production and trade dynamics in terms of the physical areas under cultivation and the prevailing terms of trade in INTSORMIL's regions of interest. There are three parts in this review. Part I summarizes the production patterns and trade flows of sorghum and millet in East Africa, West Africa, Southern Africa and Central America. It also contains an account of the sorghum and millet improvement programs around the world. Part II focuses on INTSORMIL's sorghum and millet germplasm development research works. Notable outputs of INTSORMIL's research endeavors through cultivar releases for use to the public are highlighted in this part. Part III reviews and analyses rates of return (ROR) studies conducted worldwide to measure the economic impact assessment of sorghum and millet germplasm development researches. Important findings and recommendations for future work are pinpointed in this part.

Part I

1. 1Supply Patterns and Trade Dynamics in INTSORMIL's Host Countries

1.1.1 Production in Regions of Interest

Much of the analysis in this section is based on time series data available on the FAO database on area harvested (ha), yield (kg/ha), production (tones), and seed production (tones) of sorghum and millet for the countries engaged in the INTSORMIL's program. In general, the total world area (ha) allocated to sorghum production has been in a declining trend. However, the yield productivity (kg/ha) has been slowly rising overtime. As a result of the offsetting effect of a rise in productivity, the world sorghum production (tonnes) has been on a constant/horizontal trend. The world area harvested (ha) for millet has been declining significantly over the last two decades. On the other hand, millet yield productivity (kg/ha) has been improving with increasing trend. As a result, the overall world millet production (tonnes) has been following an upward trend.

Area harvested (Ha)

From the commencement of the INTSORMIL program in 1979 up to 2008, there had been an increase in the area harvested (Ha) to sorghum in the West African host countries such as Nigeria, Niger, Mali, Senegal, Ghana and Burkina Faso and some of the East African countries such as Ethiopia and Uganda. On the other hand, Zambia, Nicaragua, Honduras, El Salvador, Kenya, Zimbabwe, and Mozambique have not shown dramatic increase in area harvested (Ha). On the other hand, the area harvested to sorghum has actually dwindled in South Africa and Botswana (Appendix 1).

Countries which allocated increasing part of their arable land to Millet during the 1979 to 2008 time period include: Niger, Nigeria, Mali, Burkina Faso, Uganda, Ethiopia, and Zambia. Other host counties such as Senegal, South Africa, Botswana, and Kenya have shown no remarkable change in the area harvested under millet. The pattern for Kenya has been somewhat irregular, with a general horizontal trend. On the contrary, Zimbabwe and Ghana have shown a declining trend in terms of the land allocated for millet production. The case for Mozambique is very irregular. The three Central American countries, El Salvador, Honduras, and Nicaragua do not have any millet production (Appendix 1).

Yield (Kg/ha)

The sorghum yield productivity (Kg/ha) trend has increased over time in Botswana, Burkina Faso, El Salvador, Ethiopia, Ghana, Honduras, Mali, Nicaragua, Niger, South Africa and Zambia. For example, the Ministry of Agriculture in El Salvador reported that the surface area in hectare sown to sorghum during the period 1999-2009 did not increase (about 105,000 ha). However, during that same period grain production increased by 33% from 140,000 MT to 186,000 MT. This is due to the dramatic yield increase per ha of 46% (603 kg/ha at an increase rate of 67 kg/year). This yield increase is attributed to the INTSORMIL's support of the CENTA (Centro Nacional de Tecnologia Agropecuaria y Forestal) sorghum varietal improvement program[2]. Similar production increases have also occurred in other Central American countries where INTSORMIL supports national programs. On the other hand, the trend for sorghum production per hectare has declined in Kenya, Mozambique, Uganda, and Zimbabwe. This figure for Nigeria and Senegal followed somewhat a horizontal trend.

The following countries have generally witnessed an increase in millet productivity (Kg/ha) over the last three decades: Botswana, Burkina Faso, Ethiopia, Ghana, Mozambique, Niger, Nigeria, Senegal, Uganda, and Zambia. There was dramatic increase in Burkina Faso, Ethiopia (right after 1980s), Ghana, Nigeria and Zambia (especially after around the year 1990) and in Niger and Uganda (around late 1990s). There has been a decline in millet productivity (yield in kg/ha) for Kenya and Zimbabwe over the last three decades and with irregular pattern for Mali and South Africa with a general horizontal trend.

1.1.2 Imports and Exports (quantity in tonnes) in regions of interest

The TradeSTAT module from FAOstat provides comprehensive, comparable and up-to-date annual trade statistics by country, region and economic country groups for about 600 individual food and agriculture commodities. Following is a summary of the imports and exports measured by the quantities (tonnes) and values ('000 USD) grouped for each of the regions (East Africa, West Africa, Southern Africa and Central America) as a percentage of the total world trade flows. For the sake of comparison and consistency, the forgoing presentation is based only on the quantity of sorghum and millet trade flows.

Sorghum

Exports

There appears to be little percentage export quantity for East Africa as a region (less than 1%), West Africa (Less than 0.8%), and lesser percentage for Central America (less than 0.4%). Relatively, Southern Africa has higher percentage of sorghum exports to the total world trade (up to 2.5%), but has steadily declined to less than 0. 5 % (Appendix 2).

Imports

There has been an increase in the percentage of sorghum imported to the East African region (from almost 0 to 5 %) and Southern Africa region (from 0 to roughly 3%) and very little or no increase in the Central American region (0 to around 1.5%). The West African sorghum imports as a percentage of world trade has gradually declined (from 2% to less than 0.5 %). The Southern African sorghum imports as a percentage of world trade has increased slowly (from almost nothing to as much as 3 %). The Central American sorghum imports as a percentage of world trade has increased at first and came back declining slowly (from 0 to more than 1 % and then kept declining to almost 0%) (Appendix 2).

Millet

[2] http://intsormil.org/smimpacts/INTSORMIL%20El%20Salvador.pdf

Exports

There have been almost no millet exports by the countries from East Africa until around the year 2000 and it has started to increase since then (almost as much as 2.5 %). There had been sizable exports from the West African region as much as 10% in the mid 1980s but has since been in a declining trend (less than 2%). The Southern Africa region has gradually increased the share of exports as a percentage of world trade (from almost 0% to close to 1.5 %). The percentage share of world millet export by the Central American region is almost nonexistent (less than 0.05%) (Appendix 2).

Imports

The percentage share of world millet imports by the East African region has remarkably increased over this period (more than 10%). This figure for the West African region has been fluctuating a great deal but with a horizontal trend. However, this region had as much as 30% share of the world millet trade around the year 2000. The Southern Africa region has also constantly increased the share of the world's millet import (from almost 0% to more than 3 %). This figure for the Central American region is almost negligible (less than 0.08%) (Appendix 2).

1. 2. International, Regional and National Sorghum and Millet Improvement Programs

The Sorghum, Millet and Other Grains Collaborative Research Support Program (INTSORMIL CRSP) is one of the major international research organizations engaged in the improvement of sorghum and millet working together with host country research organization (NARS and private organizations) in developing new technologies to improve sorghum, pearl millet and other grains production and utilization worldwide. In addition to INTSORMIL, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), a part of the Consultative Group on International Agricultural Research (CGIAR) – the consortium of CGIAR centers with 15 international centers- has a mandate to undertake research work that involve the improvement of sorghum and millet crops. ICRISAT's focus is on Chickpea, Pigeon pea, Ground nut, Pearl Millet, Sorghum and Small Millets. On top of these two international organizations, the National Agricultural Research Systems (NARS) are research stations in host countries that are mostly responsible in coordinating resources for agricultural research and development in their respective countries. There are a number of U.S. and Host countries universities with considerable amount of research and development engagements for the improvement of sorghum and millet.

1.2.1 INTSORMIL

The Sorghum, Millet and Other Grains Collaborative Research Support Program (INTSORMIL CRSP) conducts collaborative research through partnerships between 17 U.S. university scientists and scientists of the National Agricultural Research Systems (NARS), IARCs, PVOs and other CRSPs. INTSORMIL is sponsored by the USAID Bureau for Economic Growth, Agriculture and Trade (EGAT). INTSORMIL was established in 1979 under the authority of Title XII of the International Development and Food Assistance Act of 1975 to link the expertise of scientists at U.S. Land Grant

Universities with scientists in developing countries. The INTSORMIL CRSP is funded by the United States Agency for International Development and collaborating organizations in the U.S. and in host countries.

The participating U.S. Land Grant Institutions at the start of the program were: University of Arizona, Florida A&M University, Kansas State University, University of Kentucky, Mississippi State University, University of Nebraska, Purdue University and Texas A&M University. Later on, West Texas University and Ohio State University joined the program. At present, 18 U.S. scientists from the Kansas State University, Mississippi State University, Purdue University, Texas A&M University, University of Nebraska, USDA-ARS, Tifton, Georgia and West Texas University are collaborating with over 200 scientists in approximately 30 developing countries. INTSORMIL's collaborative research is currently conducted in West Africa, East Africa, Southern Africa, Central America and the United States. Present research includes the scientific disciplines of agricultural economics, agronomy, biotechnology, entomology, food science, plant breeding and genetics, plant pathology, and plant physiology (Bibliography 1984-2004). INTSORMIL's agronomists, animal nutritionists, biotechnologists, plant breeders, cereal chemists, economists, entomologists, food scientists, plant pathologists and weed scientists, from the above Land Grant Universities in The U.S. and the USDA/ARS collaborate with national research programs in East Africa, West Africa, Southern Africa and Central America.

Currently, INTSORMIL has projects in 17 developing countries of Africa and Central America, and in the United States[3]. The INSORMIL CRSP is a research organization focused on education, mentoring and collaboration with host country scientists in developing new technologies to improve sorghum, pearl millet and other grains (teff, fonio, finger millet) production and utilization worldwide. The INTSORMIL's mission is to conduct collaborative research to improve farm income and human and animal nutrition by overcoming constraints to sorghum, millet and other grains production and utilization for the mutual benefit of agriculture in the U.S. and developing countries. The focus is on increasing food security and promoting market development of sorghum and millet through targeted basic and applied research, education, short-term training and technology transfer to promote adoption and economic impact. The approach involves regional, interdisciplinary and multi-organizational teams.

The success of INTSORMIL can be attributed to the following strategies which guide the program in its research and linkages with technology transfer entities:

- Developing institutional and human capital,
- Conserving biodiversity and natural resources,
- Developing research systems,
- Supporting information networking , and

[3] Until 1988, the program had activities in the Philippines and India. Through the early 1990s, research was conducted in Brazil and Columbia. INTSORMIL's work in Brazil, Columbia, India and the Philippines was ended due to budget constraints (INTSORMIL REPORT, 2011).

- Promoting demand-driven processes

INTSORMIL currently cooperates with ICRISAT programs in Eastern, Southern and Western Africa.

1.2.2 ICRISAT

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) conducts agricultural research for development in Asia and sub-Saharan Africa with partners throughout the world. Covering 6.5 million square kilometers of land in 55 countries, the semi-arid tropic has over 2 billion people, and 644 million of these are the poorest of the poor. ICRISAT and its partners help empower these poor people to overcome poverty, hunger and a degraded environment through better agriculture.

ICRISAT is headquartered in Hyderabad, Andhra Pradesh, India, with two regional hubs and four country offices in sub-Saharan Africa. It belongs to the Consortium of Centers supported by the Consultative Group on International Agricultural Research (CGIAR).The SADC/ICRISAT Sorghum and Millet Improvement Program (SMIP) was launched in 1983, in response to a recommendation made by the SADC Heads of State. A partnership-based approach involving multiple stakeholders, commitments by participating governments and strong donor support have enabled SMIP to make significant contributions to agricultural development in southern Africa.

ICRISAT's Global research themes

Agro-ecosystem development focuses on improving rural livelihoods, attaining food security and sustainable natural resource management.

Crop improvement and management develops better crop varieties, environment-friendly and cost-effective pest management practices, efficient seed systems, and diversified uses of dryland crops.

Harnessing biotechnology for the poor complements crop improvement by applying the new science of genomics, genetic engineering and bioinformatics.

Institutions, Markets, Policy and Impacts helps formulate pro-poor policies and guides investments towards improved food security, livelihood resilience, poverty reduction and sustainable environment of the dry tropics.

1. 2.3 National Agricultural Research Systems (NARS):

National Agricultural Research Systems (NARS) are research stations in host countries mostly responsible in coordinating resources for agricultural research and development. Although the organization and specific tasks differ from country to country, in general in most countries the National

Agricultural Research Institutes, which are the backbone of NARS, dominate and mobilize the majority of resources for research.

Part II

2.1 Sorghum and Millet Varietal Improvement through INTSORMIL

Breeding genetics and varietal improvement: is one of INTSORMIL's broader areas of research and development themes to develop improved varieties of germplasm of sorghum and pearl millet, suited for practical use in improving materials available to sorghum and millet growers around the world. Initially, the emphasis was on developing germplasm with good agronomic performance, a higher degree of yield stability, and acceptable food quality and grain characteristics. At the beginning of the INTSORMIL program, out of the 41 research projects, nine projects at 5 institutions had major direction towards this phase of research (INTSORMIL, 1980). Currently there are 15 active global projects under INTSORMIL. Five of these projects are involved in breeding and varietal development. Overall, one in four of the INTSORMIL trained individuals (1979-2009) have obtained their training on breeding and varietal development. Atkople (2006) reports that about 97% of all sorghum and millet breeding efforts have been geared towards improving the grain yields with very little attention to the grain quality.

In general, the improvement programs (breeding strategies) through breeding under the mandate of INTSORMIL include: *Germplasm Collection and Conservation, Conversion, Hybrid Production, Population Improvement, Breeding for Abiotic Stress, Breeding for Biotic Factors, and Grain Quality Improvement*. Following is a tabular presentation of the breeding programs and activities and the INTSORMIL scientists and US Universities involved for each of the last three decades since the start of INTSORMIL program in 1979.

I. 1980-1989

S.No.	Project	Principal Investigator(s)/ Project Leader(s)	Remark
1	"Pearl Millet Improvement"	W. D**.** Stegmeier, and T. L. Harvey, F. L. Barnett.	Fort Hays Experiment Station, Kansas State University
2	"Sorghum Host-Plant Resistance and Genotype Evaluation" and later " Sorghum Breeding and Management of Insect, Disease, and Acid Soil Problems"	Lynn M. Gourley	Mississippi State University
3	"Adaptation Of Sorghum And Pearl Millet To Highly Acid Tropical Soils"	Lynn M. Gourley	Mississippi State University
4	" Sorghum Disease Resistance Evaluation and Pathogenicity"	Natale Zummo,	Mississippi State University
5	"Identification Of Genes Controlling The Reaction Of Sorghum To MDMV"	S. G. Jensen	University of Nebraska
6	"Breeding Sorghum For Developing Countries"	David J. Andrews	University of Nebraska
7	"Breeding Pearl Millet for Developing Countries"	David J. Andrews	University of Nebraska
8	"Breeding Sorghum Varieties and Hybrids with Improved Grain Quality, Drought Resistance and Striga Resistance"	Gebisa Ejeta	Purdue University
9	" Development Of Agronomically Superior Germplasm Including Varieties , Hybrids and Populations Which Have Improved Nutritional Value And Good "Evident" Grain Quality For Utilization In Developing Countries"	John D. Axtell and Allen W. Kirleis	Purdue University
10	"Studies on the Mechanisms of Disease Resistance and Susceptibility and Screening for Improved Resistance to Fungal Pathogens with Emphasis on Colletotrichum graminicola (Anhracnose)"	H.L. Warren	Purdue University
11	"Breeding for Productivity"	F.R. Miller, W.R. Jordan, P.C.	Texas A&M University

		Morgan , and R.A. Creelman,	
12	“Breeding for Disease and Drought Resistance and Increased Genetic Diversity”	D.T. Rosenow,Roberta, H. Smith, W. Wendit,L.E. Clark,and K. F. Schertz, Investipmi	Texas A&M University
13	“ Breeding for Insect Resistance and Efficient Nutrient Use”	Gary C. Peterson and Arthur B. Onken	Texas A&M University
14	“Development And Evaluation Of Systems For Controlling Insect Pests Of Sorghum By Integration Of Resistant Varieties , Cultural Manipulation And Biological Control”	George L. Teetes and Frank E. Gilstrap	Texas A&M University
15	“ Sorghum Improvement in Honduras and Central America”	D.H. Meckenstock	Texas A&M University

II. 1990-1999

S.No.	Project	Principal Investigator(s)/ Project Leader(s)	Remark
1	“Pearl Millet Breeding” later titled “Pearl Millet Germplasm Enhancement For Semiarid Regions” (KSU-101)	W.D. Stegmeier	Kansas State University
2	“Sorghum Breeding and Management of Insect, Disease, and Acid Soil Problems” (MSU-104)	Lynn M. Gourley	Mississippi State University
3	“ Breeding Sorghum for Tolerance to Infertile Acid Soils / Adaptation of Sorghum and Pearl Millet to Highly Acid Tropical Soils” (MSU-111)	Lynn M. Gourley	Mississippi State University
4	“Development of Agronomically Superior Germplasm Including Varieties, Hybrids and Populations Which Have Improved Nutritional Value and Good "Evident" Grain Quality for	John D. Axtell	Purdue University

	Utilization in Developing Countries (PRF-103A)” later titled “Breeding Sorghum for Increased Nutritional Value (PRF-103)”		
5	“Breeding Sorghum Varieties and Hybrids with Improved Grain Quality, Drought Resistance and Striga Resistance” (PRF-107) and later called “Development and Enhancement of Sorghum Germplasm with Sustained Tolerance to Drought, Striga, and Grain Mold”	Gebisa Ejeta	Purdue University
6	“Breeding for Productivity in Sorghum” (TAM-121) and later named “The Enhancement of Sorghum Germplasm for Stability, Productivity, and Utilization”	Fred Miller	Texas A&M University - Continued to exist in operation until the end of 1996.
7	“Breeding for Disease and Drought Resistance and Increased Genetic Diversity” (TAM -122) later modified with the title “ Germplasm Enhancement for Resistance to Pathogens and Drought and Increased Genetic Diversity”	D.T. Rosenow	Texas A&M University
8	“Increasing Resistance to Insects and Improving Efficient Nutrient Use by Genetic Manipulation for Improved Grain Sorghum Production” - (TAM-123) and later “ Germplasm Enhancement through Genetic Manipulation for Increasing Resistance to Insects and Improving Efficient Nutrient Use in Genotypes Adapted to Sustainable Production Systems”	Gary C. Peterson and Arthur B. Onken	Texas A&M University
9	“Sorghum Improvement in Honduras and Central America” (TAM-131) later titled “ Tropical Sorghum Conservation and Enhancement in Honduras and Central America”	D.H. Meckenstock	Texas A&M University - was in operation until the end of 1992
10	“Breeding Sorghum for Developing Countries” (NU-115) later titled “Breeding Sorghum for Stability of Performance Using Tropical Germplasm”	David J. Andrews	University of Nebraska
11	“Breeding Pearl Millet for Developing Countries” (NU-1 18) later named “Breeding Pearl Millet for Stability Performance Using Tropical Gemplasm”	David J.Andrews	University of Nebraska

III. 2000- 2010

S.No.	Project	Principal Investigator(s)/ Project Leader(s)	Remark
1	"Breeding Pearl Millet with Improved Performance and Stability" (ARS-204)	Wayne W. Hanna	USDA/ARS - started in 2000
2	"Breeding Pearl Millet for Improved Stability, Performance, and Pest Resistance" (ARS-206)	Jeffrey P. Wilson	USDA/ARS - started in 2004
3	"Breeding Grain Mold Resistance in High Digestibility Sorghum Varieties" (TAM-230)	Dirk Hays	Texas A&M University -started in 2005 and terminated in 2008
4	"Breeding Sorghum for Increased Nutritional Value" (PRF-103)	John D. Axtell	Purdue University - had been in operation until the end of 2001
5	"Development and Enhancement of Sorghum Germplasm with Sustained Tolerance to Biotic and Abiotic Stress" (PRF-207) and then "Breeding Sorghum for Improved Resistance to Striga and Drought in Africa" (PRF 101)	- Gebisa Ejeta	Purdue University - The second project started in 2008
6	"Enhancing the Utilization of Grain Sorghum and Pearl Millet through the Improvement of Grain Quality via Genetic and Nutritional Research" by (KSU 220)	Mitch Tuinstra, Joe Hancock, William Rooney and Clint Magill	Kansas State University -started in 2005
7	"Developing Sorghum with Improved Grain Quality, Agronomic Performance, and Resistance to Biotic and Abiotic Stresses" (PRF 104)	Mitch Tuinstra	Purdue University - started in 2008
8	"Breeding Sorghum for Improved Grain, Forage Quality and Yield for Central America"	William Rooney	Texas A&M

	(TAM 101)		University - started in 2008
9	"Germplasm Enhancement for Resistance to Pathogens and Drought and Increased Genetic Diversity" (TAM-122)	Darrell T. Rosenow	Texas A&M University - terminated by the end of 2004
10	"Germplasm Enhancement through Genetic Manipulation for Increasing Resistance to Insects and Improving Efficient Nutrient Use in Genotypes Adapted to Sustainable Production Systems" (TAM-123) and later named " Breeding Sorghum for Improved Resistance to Biotic and Abiotic Stresses and Enhanced End-Use Characteristics for Southern Africa" (TAM 102)	Gary C. Peterson and Arthur B. Onken , the project later was led by PI Gary C. Peterson	Texas A&M University
11	"Breeding Pearl Millet and Sorghum for Stability of Performance Using Tropical Germplasm" (UNL-2 18)	David J. Andrews	University of Nebraska - had been in place until the end of 2000

2.2. Current Varietal Development Investments

Currently there are 15 active global projects under INTSORMIL's management. One in three of these projects is involved in breeding and varietal development.

2.2.1 INTSORMIL's Notable Achievements by Target Regions

During the last three decades, there has been huge number of breeding lines, parental stocks, germplasm and cultivars released in INTSORMIL's host countries around the world. INTSORMIL reports reveal that there have been remarkable breeding success stories such as the release of the first hybrid sorghum Hageen Dura (HD-1) in Sudan, a superior hybrid with yields of over 150% of those of improved local varieties under irrigated and rainfed conditions; and the introduction and release of Sureno sorghum variety in Honduras with superior grain quality, high yield potential, disease resistance, and dual purpose use for both grain and forage. Numerous others have been released in other African countries such as Mali, Niger, Nigeria, Zambia and Ethiopia. In the forgoing, highlights of the notable breeding and varietal development achievements scored through the INTSORMIL program are briefly presented. Note that the release and exchange of breeding lines, for example parental sorghum lines/germplasm released from INTSORMIL programs for use in commercial hybrid production in the United States and elsewhere are not included in this review[4].

2.2.1.1 Sorghum and Millet Germplasm Development Research in East Africa

Sudan

Hageen Dura-1

The Sudan is one of the countries INTSORMIL had an interest for collaboration and field work during the beginning of the program. The Sudan was targeted as the principal initial area for field operation (1980, Annual Report). Breeding programs were well underway in Sudan by the early 1980s for high yield, drought resistance and disease and pest resistances.

In collaboration with scientists at Agricultural Research Corporation (ARC) the INTSORMIL/ ICRISAT/Sudan Cooperative breeding program released the first sorghum hybrid, Hageen Dura-1(Tx623 x KI567) in January 1983. The female line Tx623 (from INTSORMIL) was used due to its wide adaptation, high yield potential and drought resistance. The female line ATx623 was crossed with Karper-1597 by ICRISAT-Sudan Cooperative program staff at that time (Dr. Gebisa Ejeta-who is now a principal investigator and East African regional coordinator for INTSORMIL's projects). Hageen Dura-1 (HD-1) is a superior hybrid with yields of over 150% of those of improved local varieties under irrigated and rainfed conditions. HD-1 possesses several important attributes including high yields, drought tolerance, and good grain quality characteristics that helped its rapid spread and wide acceptance by farmers (INTSORMIL Annual Report, 1982/83). In the early 1990s, records (INTSORMIL Annual Report, 1995) show that internal rates of return to the introduction of Hageen-Dura 1 without further extension of the production area were 23% for low fertilizer levels and 31% for high fertilizer use levels.

Striga tolerant/resistant line (SRN-39)

Almost 10 years later after the release of Hageen Dura 1, as a result of ARC/ICRISAT/INTSORMIL/Sudan Cooperative collaborative program, a Striga tolerant line was also released for production in Sudan in 1991. General agronomic qualities of this line were great. In one area alone about 1200 ha of SRN-39 was grown in 1992. SRN-39 and other possible sources of resistance to *Striga* have been used in breeding programs in Mali, Niger and other countries to improve adaptation, yield potential and agronomic characteristics. The *Striga* resistant line had also been tested

[4] For example, in 1989, reports show that germplasm lines resistant to sorghum midge (21 lines) or biotype E greenbug (10 lines) have been developed and released (INTSORMIL annual report, 1989). In another example, a group of 40 diverse sorghum germplasm lines were released to the private industry cooperatively with F.R. Miller (TAM-121) and L.W. Rooney (TAM-126) (INTSORMIL annual report, 1990). From 1979-1993, a total of 415 germplasm lines, populations, parental lines, and converted exotic lines have been released. During 1997-98, 62 parental lines of sorghum and 7 of grain pearl millet were released by the Nebraska INTSORMIL collaborating breeder (INTSORMIL annual report, 1998). By late 2000, since the inception of the INTSORMIL program, the total released fully converted lines were 700 (INTSORMIL annual report, 2000).

on field stations or in farmers' fields, or both, in the following countries: Ghana, Senegal, Mali, Niger, Sudan, Rwanda, Mozambique, and Eritrea (INTSORMIL FINAL REPORT, 1990-1995).

Ethiopia

***Striga* resistant/tolerant varieties**

Successful releases of *Striga* resistant sorghum cultivars have been made by Purdue University/INTSORMIL/NARS in Ethiopia. The three cultivars are known by the local names of "Gubiye" (P9401) , "Abshir" (P9403) and Brhan (PSL5061). The first two cultivars were released in 1999/2000 and the third cultivar was released in 2002. Good quality seed of 'Gubiye' and 'Abshir' were produced in large quantities both at Purdue University and Melkassa Agricultural Research Center which were distributed to farmers selected to participate in the Integrated Striga Management (ISM) project. Nitrogen fertilizer in the form of urea and diammonimum phosphate (DAP) were purchased from the local market and provided to selected participants. Tied ridgers were fabricated in the local industrial area in Nazret from a design provided by the Melkassa Research Station. Presently, over 100,000 farmers are growing *Striga* resistant sorghum varieties in Ethiopia (Tesso et al. 2006).

2.2.1.2 Sorghum and Millet Germplasm Development Research in West Africa

Niger

Drought tolerant sorghum hybrid – NAD-1

In 1992, a sorghum hybrid, NAD-1, was released through collaboration of research between INTSORMIL, INRAN and Purdue University (INTSORMIL annual report, 1997). This drought tolerant sorghum hybrid designated NAD-1 (NAD-1 = Tx623 x MR732) had proven to be highly productive and well adapted in Niger. The grain quality is acceptable for local food preparations. The yield at the time of release was approximately twice the yields of local varieties. Overall, the average yield of NAD-1 between 1986 and 1994 was 2,758 kg/ha on-station, ten times the average yield of the farmer in Niger (273 kg/ha). In 1993, the farm level plots showed the average farmer yield for the Konni and Jirataoua region was 2,365 kg/ha for NAD-1. In 1994, NAD-1 yielded an estimated 1,725 kg/ha (Say), 3,500 kg/ha (Jirataoua), 3,800 kg/ha (Cerasa), and 4,600 kg/ha (Konni) for an overall farmer yield of more than 3,000 kg/ha. This is compared to the national average of 273 Kg/ha.

Results of Regional Trials indicated a wide adaptation of NAD-1 in other countries of the region indicating possible research spillovers (INTSORMIL FINAL REPORT, 1990-1996). Other notable breeding stories include the release of Sepon 82, F1-223 (hybrid), SSD35, SRN39 and P901-903 (Striga-resistant) , MM, and 90SN7 (INTSORMIL ECONOMIC IMPACT STUDY,2006).

In addition to working with new sorghum varieties and tests, the Guidad Idar community has also actively worked with INRAN/INTSORMIL in new millet varieties—such as HKP, Souna-3, and Zatab (INTSORMIL ECONOMIC IMPACT STUDY, 2006).

Midge resistant varieties:

Reports also show that as a result of serious midge infestation on sorghum, farmers in Niger had been advised to quit using high-yielding Sepon-82 and NAD-1 cultivars. Through relentless effort of the work of INRAN/INTSORMIL to develop and release midge-resistant lines, the farmers received new midge-resistant varieties, which have achieved a strong positive impact and produced high yields. Farmer interviews revealed that they averaged approximately 3 tonnes per hectare in yield from the midge-resistant variety, twice what they could have obtained from their normal varieties even when they escape midge. (INTSORMIL ECONOMIC IMPACT STUDY, 2006).

Mali

During the early days of INTSORMIL, Mali was one of the sites with a potential foresight for the program in Africa. Reports (INTSORMIL, 1982/83) show that considering the interest of all the stakeholders involved in the collaborative work, Mali had been identified as a promising host country to best meet the mandate under the Title XII program.

Over the years, so many successful varietal releases have been made through the INTSORMIL collaboration program. Notable among these were the release of seven improved sorghum Malisor lines (84-1 to 84-7). These Malisor lines (84-1 to 84-7) have different maturities and characteristics for the various regions of Mali. Chief among these lines was the Malisor 84-7 with excellent head bug resistance (INTSORMIL, 1989). There had been further releases of two more Malisor lines (Malisor 92-1 and Malisor 92-2). The reports also indicate the release of tan-plant Guinea type improved sorghum cultivars called N'Tenimissa (Bimbiri Soumale x 87CZ-Zerazera) and so many other derivatives of this cultivar, such as Wassa (97-SB-F5DT-63), Kénikédiè (97-SB-F5DT-64), Darrellken (99-BE-F5P-128-1), Niéta (97-SB-F5DT-74-2), Zarra-blè (96-CZ-F4P-98), and Zarra-djé (96-CZ-F4P-99) which were crosses between (N'Tenimissa*Tiemarfing). INTSORMIL economic impact assessment study (2006) documents that two of these improved sorghum varieties "Nieta" and "Waasa" were grown with 17.5 and 14.5 hectares respectively.

2.2.1.3. Sorghum and Millet Germplasm Development Research in Southern Africa

High yielding hybrids such as ZSV-15, WP-13, MMSH -413, MMSH-625 and MMSH-1365 have been released for use in Southern Africa region, especially in Zambia. Besides, INTSORMIL's reports show that there had been distribution of the Striga resistant variety, SRN 39, to Mozambique.

2.2.1.4 Sorghum and Millet Germplasm Development Research in Central America

INTSORMIL reports document that all over Central America, there has been a rapid growth of hybrid sorghum seed sales for use in production of sorghum grain for feed. For example, in 1995, it was estimated that 35% of the sorghum area was planted to hybrids.

Puerto Rico

In 1989, a collaborative work between Georgia, Texas, and Puerto Rico resulted in the release of white seeded, tan plant, food type, foliar disease resistant population, GTPP7R (H) C5. This sorghum variety carries high levels of resistance to anthracnose, rust, and other foliar diseases in a diverse genetic background, as well as possessing grain with desirable food properties (INTSORMIL, 1989).

Mexico

In 1983, Mexico released two hybrids - BJ-83 and BJ-85 - arising from INTSORMIL materials introduced previously. At the same time there had been a major improvement in yield, disease resistance, and quality of sorghum resulting from INTSORMIL collaboration (INTSORMIL EEP, 1988).

Honduras

Records show that significant number of cultivar releases have been made in Honduras through INTSOTMIL's collaboration. Most notably, three food-type high yielding sorghum maicillo cultivars have been released in the early to mid 1980s. These were Tortillero (CS3541 Sel.), Catracho (Tx623 x Tortillero), and Sureno [(SC423 x CS3541) E35-11-2-2] released in 1982, 1984 and 1985 respectively. Sureno, in particular, has widespread acceptance by Honduran farmers because of its superior grain quality, high yield potential, disease resistance, and dual purpose use for both forage and grain. INTSORMIL reports show that Sureno was the first sorghum cultivar released that has found its way into informal seed markets in Honduras.

The released cultivars provide more stability to sorghum production through drought, insect and disease resistance. They give superior yields of quality sorghum (INTSORMIL EEP, 1988). There are reports that indicate the enhanced maicillos have produced up to 58% more grain yield than their maicillo parent and are resistant to sorghum downy mildew (INTSORMIL, 1989) and drought, insect and disease resistance. Two improved varieties, Gigante Mejorado and Porvenir Mejorado had also been released in Honduras.

In early 1990s, INTSORMIL's socioeconomic research had shown that the internal rate of return to the development of Sureno and Catracho has been estimated at 32%. These new sorghum cultivars have economically benefitted small farmers dependent on small-acreage hillside farms, the poorest farmer segment in Honduras (INTSORMIL FINAL REPORT, 1990-1996). Sureno has accepted widespread acceptance throughout the sorghum growing regions of Honduras. Around the year 1992, there were estimates that 15% of the crop area of the small farmers of southern Honduras was planted to Sureno (INTSORMIL Annual Report, 1992).

An impact assessment exercise completed in July, 1996 aimed at measuring the impact of the new cultivars developed through the SRNIEAP/INTSORMIL program in Honduras, El Salvador, and Nicaragua indicated that benefits from the varietal improvement research in the three countries ranged from $437,000 per year in Nicaragua, $600,000 in Honduras to $1,900,000 per year in El Salvador. Estimates include only the benefits accruing from the adoption of cultivars developed by the public research systems. Only the Honduras benefits can be totally credited to the SRNIEAP/INTSORMIL program (INTSORMIL FINAL REPORT, 1990-1996).

Guatemala

The sorghum hybrid (Tx623 X Tortillero) had been widely used in Guatemala with a marketing name as ICTAM777. Two improved varieties, Gigante Mejorado and Porvenir Mejorado, released in Honduras had been released in Guatemala as well. Other successful releases involved forage hybrids for green chop use in intensive dairy production such as CENTA SS-44 (ICSA275xTX2784), and INTA Forajero.

Colombia

In 1991, two varieties, Sorgo Real 40(156-P5 Serere-1) and Sorgo Real 60 (MN 4508) were released in Colombia. These cultivars produce profitably in soils with 60% Al saturation, immediately making more than 200,000 hectares of marginal farm land available for sorghum production in Colombia alone. Later in 1993, an acid tolerant cultivar, Icaravan I (IS 307 1), was released.

Nicaragua

In Nicaragua, varieties widely adapted for various regions of the country were released. White-grained, early maturing varieties (INTA Trinidad and INTA Ligero) adapted to low rainfall areas with less than 800 mm per year; (INTA CNIA) white-grained variety for higher rainfall areas with over 800 mm per year; a hybrid cultivar with the name ZAM-ROJO. Recently, in 2008, INTA RCV, INTA SR-16 and INTA Forrajero were also released.

El Salvador

The Honduran variety Sureño, with the name CENTA SV-3 and variety RCV used to maintain milk production during the dry summer season had been released in El Salvador.

During the last three decades of INTSORMIL's lifespan, a summary of the officially released cultivars (varieties/hybrids) through INTSORMIL/US/host country collaborations is provided in Table 1. Note that the release and exchange of seed parents, germplasms and breeding lines [5], for example parental sorghum lines/germplasm released from INTSORMIL programs that have been used in commercial hybrid production in the United States and elsewhere are not included in this table. Besides,

[5] The germplasm releases were designed so that sorghum breeders could have early access to new project material with potential for breeding new seed parents. Germplasm was exchanged between countries and with U.S. scientists (INTSORMIL annual report, 1989). For example, in 1989, reports show that germplasm lines resistant to sorghum midge (21 lines) or biotype E greenbug **(10** lines) have been developed and released (INTSORMIL annual report, 1989). In another example, a group of 40 diverse sorghum germplasm lines were released to the private industry cooperatively with F.R. Miller (TAM-121) and L.W. Rooney (TAM-126) (INTSORMIL annual report, 1990). From 1979-1993, a total of 415 germplasm lines, populations, parental lines, and converted exotic lines have been released. During 1997-98, 62 parental lines of sorghum and 7 of grain pearl millet were released by the Nebraska INTSORMIL collaborating breeder (INTSORMIL annual report, 1998). By late 2000, since the inception of the INTSORMIL program, the total released fully converted lines were 700(INTSORMIL annual report, 2000).

improved cultivars released for use for multiple countries such as in sub-Saharan Africa and Latin America is not included here. The release of cultivars at this table may be taken as the conservative estimate. A complete and detailed list of all the released varieties is provided in Appendix 3.

Table 1. Summary of the officially released cultivars (varieties/hybrids) through INTSORMIL/US/host country collaborations.

No.	Country	Number of Released Varieties
1	Sudan	4
2	Ethiopia	3
3	Kenya	1
4	Niger	8
5	Nigeria	1
6	Mali	10
7	Zambia	4
8	Tanzania	2
9	Mexico	2
10	Honduras	5
11	Guatemala	4
12	El Salvador	2
13	Nicaragua	9
14	Puerto Rico	1
15	Colombia	4
16	China[6]	1

[6] The line Tx622 (a sister line to Tx623 in Hageen Dura) had been introduced to China, and was used in hybrids planted on tens of thousands of hectares (INTSORMIL FINAL REPORT, 1990-1995).

Part III

Rates of Returns to Sorghum and Millet Agricultural Research and Development

Introduction

Over the last two decades, the total world area (ha) allocated to sorghum production has been in a declining trend (FAO, 2011). However, the yield productivity (kg/ha) has been slowly rising overtime. As a result of the offsetting effect of a rise in productivity and a decline in harvested area, the world sorghum production (tonnes) has been on a horizontal trend. During this same period, the total world area harvested (ha) for millet has also been declining significantly. However, millet yield productivity (kg/ha) has been improving with increasing trend. As a result, the overall world millet production (tonnes) has been trending upward (FAO, 2011).

Sorghum is a major cereal and food source for sub Saharan Africa and India. A sizable portion of the world sorghum and millet production arises from sub-Saharan Africa and Asia (FAO, 2011). In 2008, the total world sorghum and millet production quantities were in the amount of 66 million and 35 million tonnes respectively. Out of these, a total of 83% of the sorghum quantity and 97% of the millet quantity were produced by the top 20 producing countries. Out of these 20 countries, 50% and 95% were from Africa and Asia for sorghum and millet respectively. For Millet, 50% out of the top 20 quantity producing countries comes from African countries. Two out of the top 5 highest producing countries for sorghum are from Sub-Saharan Africa and three out of the top 5 highest producing countries for millet are from Sub-Saharan Africa (Figures 1 and 2).

In 2008, the United States was the leading sorghum producer in the world followed by Nigeria, India and Sudan. In an un-tabulated analysis, the leading sorghum exporters are the United States and Argentina and the leading importers are Spain, Mexico, and Japan. For millet, the leading importers are Yemen, Belgium and United Arab Emirates. The leading exporters are India, distantly followed by United States of America and Ukraine.

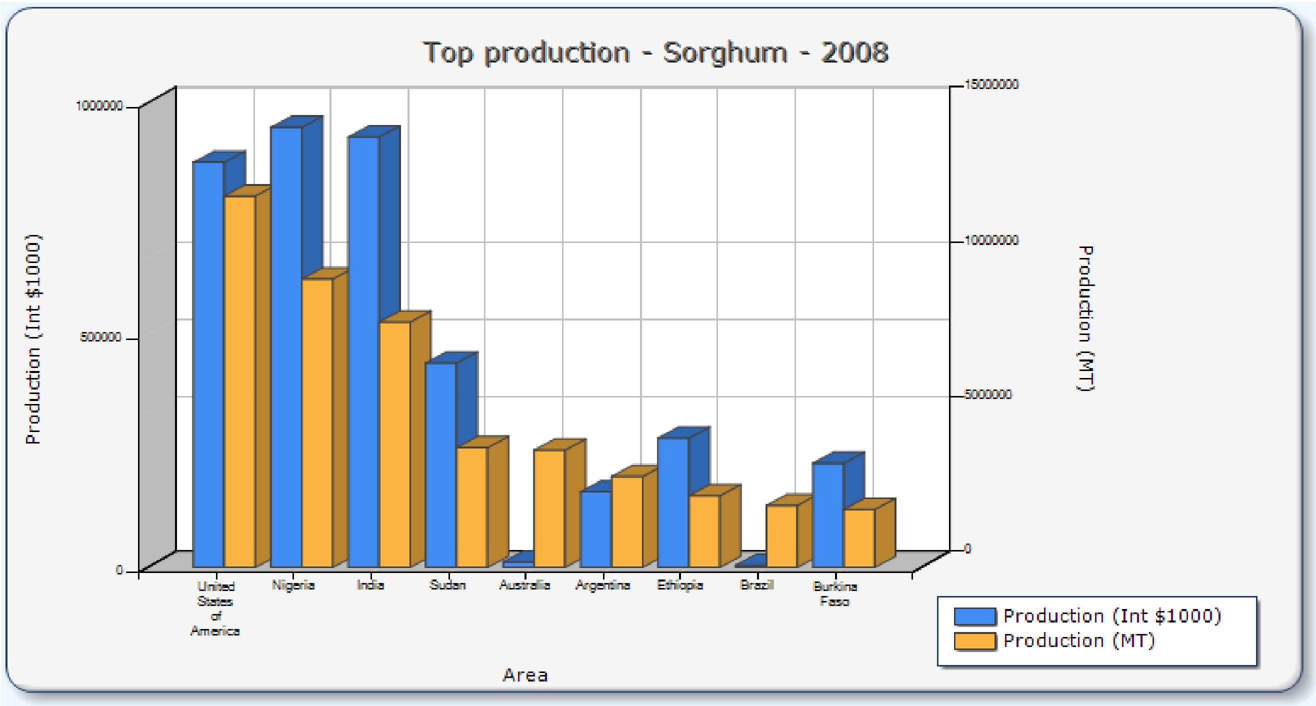


Figure 1 Top world sorghum producing (MT) countries in 2008

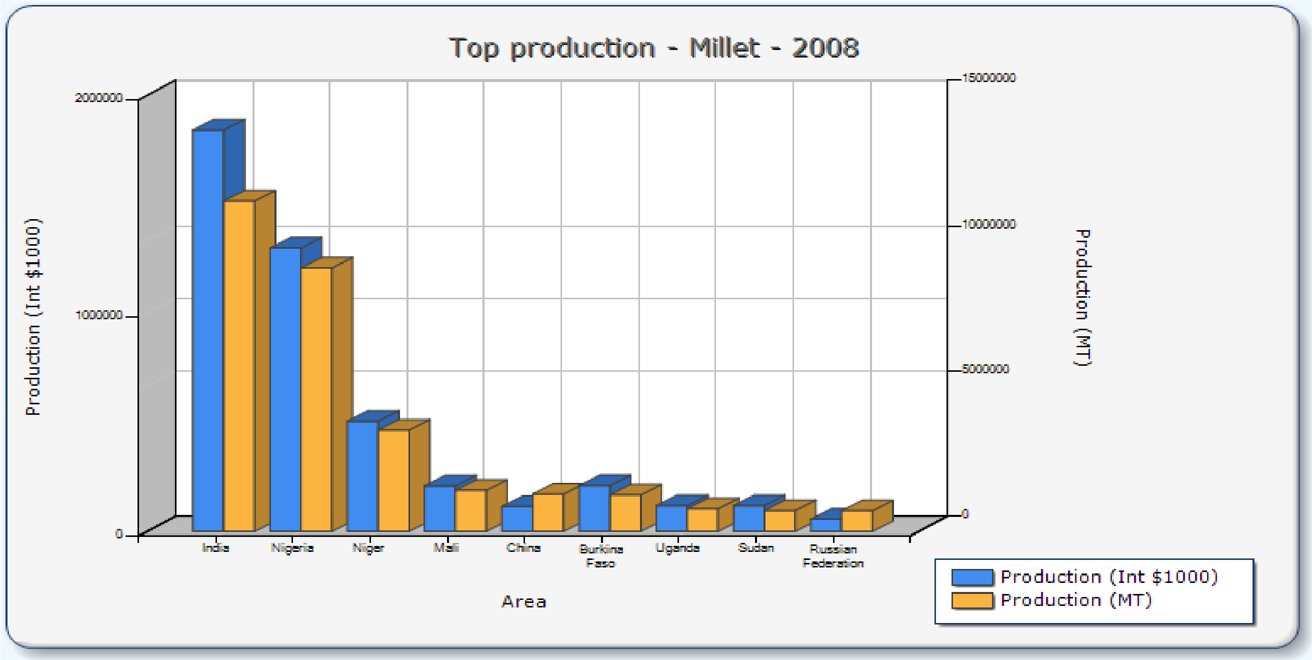


Figure 2 Top world millet producing (MT) countries in 2008

Source: FAO , 2011

Agricultural Research and Development and Impact Assessment

Agricultural research and development is key to productivity growth for agriculture and economic development. Worldwide research on sorghum and millet and other grains is mobilized and coordinated on various fronts. The Sorghum, Millet and Other Grains Collaborative Research Support Program (INTSORMIL) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) are the two major international organizations working in collaboration with host countries' National Agricultural Research Systems (NARS), Universities, private organizations, and others in developing new technologies to improve sorghum, pearl millet and other grains production and utilization worldwide.

The feasibility of investing in agricultural research and development (R&D) has always been an issue of debate among scholars, policy makers, and stakeholders. To secure continuous funding for agricultural R&D, the return on such investment must be justified using social, economic, and environmental metrics. Rates of return estimates are summary measures of the social returns obtained from investments in R&D. The Internal Rate of Return (commonly referred to as ROR) is the most popular metric used to measure the return on investment on agricultural R&D. However, it is by no means a complete measure of the return on investment, because the variables used to compute ROR may not capture the impact of the overall investment on R&D. For example, the adoption rate is an important variable used to construct ROR, however, even though the actual R&D investments and the outputs thereof (e.g. released varieties) have really been successful, the adoption rate may have been very low not due to the failure of the new technologies, but because of the prevailing policy or because of other complementary inputs such as fertilizer, or due to weaknesses in the extension services or lack of functioning input and output markets which may not be directly related to the introduced technology. Hence, studies based on ROR should recognize these conditions.

A recent comprehensive meta-analysis of rates of returns study by Alston et al. (2000) concluded that in general agricultural R&D has paid off handsomely for society. Alston et al. (2010) noted that specific rate of return findings differ depending on methods and modeling assumptions, such as assumptions concerning the research lag distribution, the nature of the research-induced technological change, and the nature of the markets for the affected commodities. This chapter is a review and analysis of the economic impact of research and development on sorghum and millet measured through return to research on a global coverage.

Economic Impact Assessment

Because of the nature of the available data and the limitations of the project funds and time, the current study is specifically confined to economic impact assessment. It is worth noting that, in most cases, unlike industrial technology improvement investment, the study of agricultural R&D mainly focuses on investments in which there appears little or no negative externalities to warrant a study of other impact assessment studies such as environmental impact assessment studies.

The importance of impact assessment exercise is becoming more and more apparent everyday as organizations, research managers, funding institutions are increasingly allocating resources for conducting such activities and at the same time donor agencies demanding the execution of such exercises for accountability purposes. Agricultural research organizations are under continual pressure to conduct impact assessment of their research activities and to better integrate the social, economic and environmental considerations in research planning and implementation. For example, for the

INTSORMIL program, in 2009 one of the initiatives recommended by USAID was to conduct impact assessment studies of each of the four INTSORMIL regional programs; Central America, East Africa, West Africa and Southern Africa.

Data Collection and Methods

To identify studies for the review, we started with the latest publications available online or on print and reviewed the citation reference sections. Each of the references cited was reviewed for information on impact assessment studies on sorghum and millet. Based on this information, we traced again the relevant impact assessment studies on sorghum and millet. We then reviewed the reference sections of each of these studies. This process was repeated until no more relevant reference citation was found on the reference sections. In order to do so, we employed online search engines such as Google scholar, K-State data bases, and Consultative Group on International Agricultural Research (CGIAR)'s Impact Assessment publications database using key word searches. We have also applied K-State's interlibrary loan services to obtain materials that were not readily available online. We have also made personal contact via email and phones with some of the authors to retrieve r of the relevant studies.

Determinants of Estimated Rates of Return to Sorghum and Millet R&D

Alston et al. (2000) organized the factors that account for the variation in measured returns to agricultural R&D into four broad categories:

- Characteristics of the rate of return measures (measure, **m**)
- Characteristics of the analysts performing the evaluation (analyst, **a**)
- Characteristics of the research being evaluated (research, **r**)
- Features of the evaluation (evaluation, **e**)

A general model was developed by hypothesizing the functional relationship (*f*) between the rate of return measure (*m*) and the explanatory groups as:

$$m = m^*(\mathbf{r}) + v\,(\mathbf{a}, \mathbf{r}, \mathbf{e}, u) = f\,(\mathbf{a}, \mathbf{r}, \mathbf{e}) + u,$$

where a bold letter indicates a vector of the corresponding characteristics. The measure m is equal to the true value of what was being evaluated m^* plus the measurement error v. The true measure m^* depends only on the characteristics of the research being evaluated (r), whereas the measurement error v depends on the same characteristics of the research but also on various other explanatory factors, as well as the truly random component u. Building on the Alston et al. (2000) model, the current study is specifically geared towards identifying and developing those variables relevant to sorghum and millet commodities. Only a summary of the model is provided here, however, for a comprehensive description of the model and variables included in the meta-analyses the reader is referred to Alston et al. (2000).

Characteristics of the Rate of Return Measure (*m*)

Variables that are pertinent to the characteristics of the rate of return may include whether the ROR measure was ***real or nominal, marginal or average, ex ante or ex post, social or private***. These variables could potentially contribute to the variation in the RORs across the studies.

Analyst Characteristics (a)

The characteristics of the analyst may provide information on possible biases or precision, arising from the person or group who measures a rate of return having an interest in certain results from the study or having access to relatively good information about the research being evaluated. Some variation among studies may be associated with variations among individuals in what they work on, how they go about their work, and what procedures they use. Given that a significant amount of the R&D investment on sorghum and millet is affiliated with specific organizations and institutions, the question of whether or not the evaluation of R&D work represents a ***self-evaluation*** forms an important factor that may tend to affect the results on rates of return favorably or unfavorably. For example, Alston et al. (2000) explain that in many cases the rate of return to research expenditures is estimated by researchers associated in some way with the research or the research institution being evaluated. They contend that self-evaluation could possibly introduce some upward bias in the estimate. Conversely a self-evaluator may better understand the research being evaluated or have better access to data and other information and may reduce some biases. In anyway, the direction of any such effect is unclear.

Since a significant amount of sorghum and millet R&D is conducted by international research organization such as INTSORMIL, ICRISTAT, or Universities, a variable to address this feature is relevant for the analysis.

Whether or not the research work was published may also have a bearing on the rate of return result**.** Alston et al. (2000) note that this aspect reflects the types of reviewer scrutiny to which the work was subjected, but the prepublication review process may also discriminate against studies that generate rates of return that fall outside the range of “conventional wisdom” prevailing in the profession at the time or that it may not be desirable to publish.

Research Characteristics (r)

The rate of return is likely to vary systematically with changes in the characteristics of the research itself. The current study is benefits from controlling the sources of variations that are associated with the research characteristics, for example the need to classify the studies by commodity classes. Because this study is confined to sorghum and millet only, there is no need to classify the ROR studies by commodity classes. Due to inadequate number of observations, observations were aggregated across field of sciences *(basic, applied, and extension)* and the type of technology *(yield enhancement, pest or disease control, management, post farm handling)* although the majority of studies were on crop genetic improvement**.** It was not possible to extract information for all the studies on the time period when the research being evaluated was conducted and when the results were adopted and the geographical region where the R&D was conducted and the geographical region where the results were adopted. Data on the type of institution that conducted the R&D (university or research institute); and the scope of the research being evaluated (an entire national agricultural research system, the entire portfolio for an institute, or a particular program or project) were collected.

Evaluation Characteristics (e)

Several characteristics of the analysis have implications for the measure of the research-induced change in yield, productivity, or the supply shift; others have implications for the size of measured benefits and costs of R&D for a given research-induced supply shift. At a fundamental level such choices include whether the study involves an explicit economic surplus analysis, with a formal supply and demand model, or whether it leaves the model implicit and uses an approximation based on a percentage research-induced supply shift multiplied by the initial value of production. The majority of the studies reviewed used explicit economic surplus analysis, and so this set of variables may not be considered as a source of variation for this particular study.

Studies that use explicit surplus measures involve choices about the functional forms of supply and demand (linear or constant elasticity) and the nature of the supply shift, whether it was pivotal or parallel. Given the relative homogeneity in the use of explicit economic surplus analysis method, there was enough variation among the studies reviewed in terms of the supply shift assumptions and hence using these variables in the present study.

Descriptive Statistics of the variables reviewed

Although the *real or nominal* variable was defined at first, this measure was not clearly indicated for many of the studies reviewed and hence this variable was not included in the analysis. Over all, there were 22 publications and 49 point estimates reviewed for the internal Rate of Return (ROR) studies (there were additional adoption studies as well). All except one of the studies computed the ROR estimates. For the one study, however, we calculated the ROR based on reported estimates of benefits versus corresponding research costs. A large majority of the studies were ex-post type of analyses (68 % for both publications and point estimates), indicating that most of the ROR studies on sorghum and millet were conducted to evaluate the consequences of past R&D investments. If we look at the African continent for example, all except one study were an ex-post type of analyses. Most of the studies (86% of the publications and 74% of the point estimates) computed an average RORs compared to marginal RORs. This is as a result of the widespread use of the economic surplus method to calculate the benefits of R&D to society. In addition, all of the studies reviewed calculated social (as opposed to private) rate of returns (Table 1). This is particularly true in the African case studies, because all of the technologies developed originated through the use of public funds in the host country National Agricultural Research Systems (NARS) and from international partners such as ICRISAT, INTSORMIL, and collaborating institutions.

Sorghum and millet grow in very harsh environments where other crops do not grow easily. Millions of the poorest people in the semi-arid tropics of Africa and Asia consume sorghum and millets. In general, due to these production and peculiar consumption characteristics of sorghum and millet around the world, the sorghum and millet ROR studies are confined to specific geographic regions of the world. More than half of the impact assessment studies (64% of the publications) were conducted in the Sub-Saharan Africa, followed by almost a quarter of the studies being in the United States (23%) and the remaining small percentage in India (4.5%) (Table 2).

Table 1: Profile of Rate of Return measure characteristics

Characteristic	Number		Share of respective total	
Nature of evaluation	**Publications**	**Estimates**	**Publications**	**Estimates**
	(count)		(percentage)	
Ex ante	4	12	18.2	24.5
Ex Post	15	33	68.2	67.3
Unclear	3	4	13.6	8.2
Average or marginal rate of return				
Average	19	36	86.4	73.5
Marginal	1	10	4.5	20.4
Unclear	2	3	9.1	6.1
Private or social rate of return				
Private	0	0	0	0
Social	20	46	90.9	93.9
Unclear	2	3	9.1	6.1

Table 2: Geographical characteristics of evaluated sorghum and miller R&D studies

Characteristic	Number		Share of respective total	
	Publications	**Estimates**	**Publications**	**Estimates**
	(count)		(percentage)	
Africa	14	19	63.6	38.8
United States	5	24	22.7	49
India	1	3	4.5	6.1
Unclear	2	3	9.1	6.1

More than half of the studies (59 % of the publications) reported the two major sorghum and millet improvement organizations around the world - the INTSORMIL and ICRISAT -as the primary source of the technology (e.g. breeding materials to develop the sorghum and millet technologies). This is followed by other categories (32% of the publications) such as private organizations and universities that are not directly affiliated to these two institutions (Table 3).

Table 3: Rates of Return Studies by Institutional Sources of Technology for Sorghum and Millet (e.g. Sources of Breeding Material)

Characteristic	Number		Share of respective total	
	Publications	**Estimates**	**Publications**	**Estimates**
	(count)		(percentage)	
INTSORMIL only	2	7	9.1	14.3
ICRISAT only	10	14	45.5	28.6
Both INTSORMIL and ICRISAT	1	1	4.5	2.0
Other	7	24	31.8	49.0
Unclear	2	3	9.1	6.1

Table 4: Rates of Return Studies by Commodity of Analysis

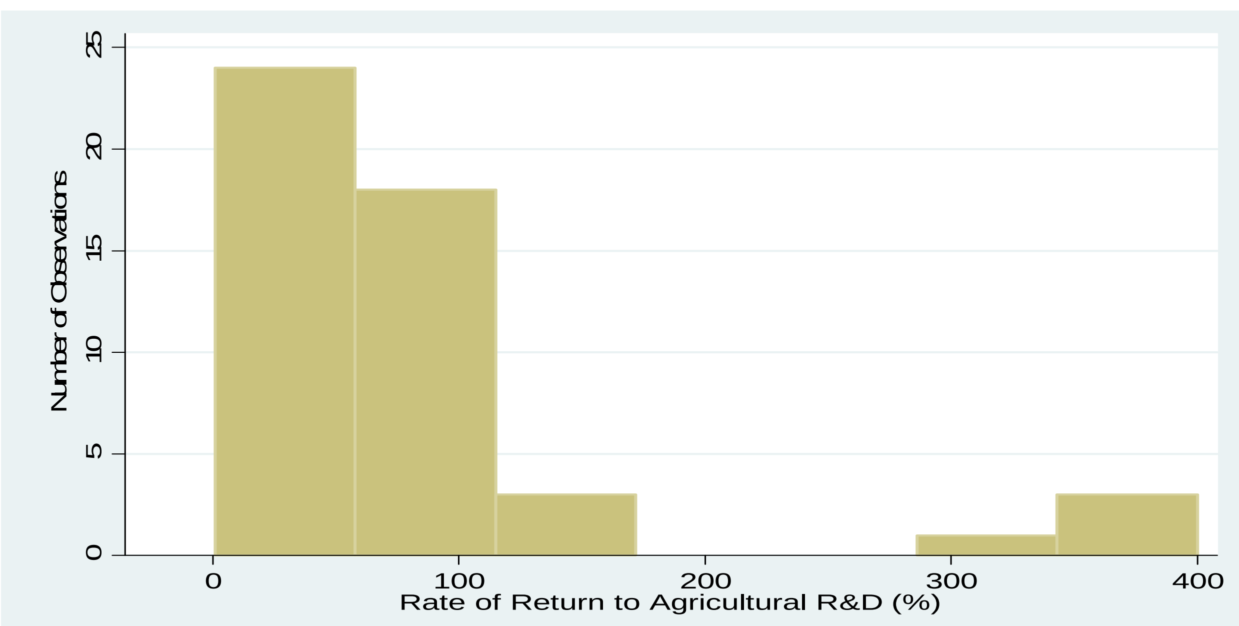
Characteristic	Number		Share of respective total	
	Publications	**Estimates**	**Publications**	**Estimates**
	(count)		(percentage)	
Sorghum	16	37	72.7	75.5
Millet	2	3	9.1	6.1
Both	3	7	13.6	14.3
Unclear	1	2	4.5	4.1

Even though both Sorghum and millet are included in the review of studies, close to three quarter of the studies focused only on sorghum (73% of the publications) and one tenths of the studies (9% of the publications) dealt only with millet (Table 4). This result may be because of the economic importance and wide range usage of sorghum in the countries where the studies were conducted and the relatively higher proportion of investment expenses allocated by research institutions on sorghum than on millet.

Distributional Patterns of Rates of Return

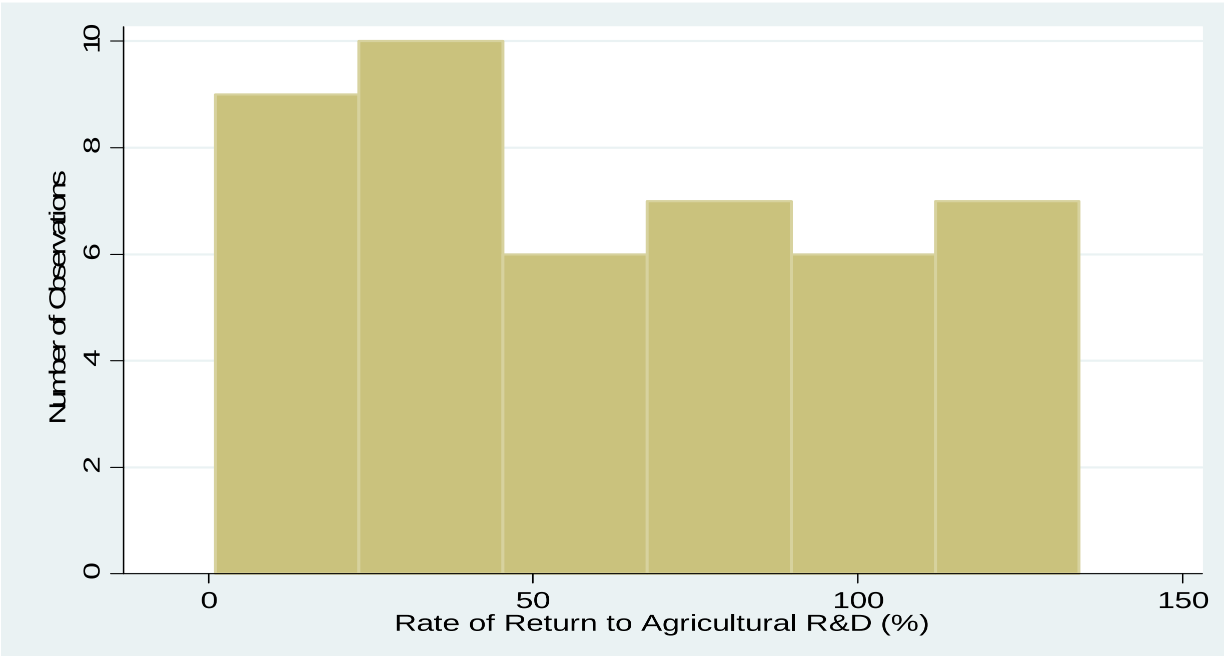
The distribution of the ROR to sorghum and millet for all the observations appears to have a bimodal distribution (Figure 1). The average ROR for this set of data was 84.71 and around 10 % of the studies have an ROR of less than 10% and 16 % of the studies have an ROR of less than 15%.Two publications (4 point estimates) have reported an ROR of close to 400 percent. These two studies were conducted in the United States and the very high rates of returns may be due to the better technology packages available in the United States that facilitate the adoption and diffusion of the technologies much easier compared to other less developed countries where the adoption and diffusion of the new technologies are hampered by so many critical factors. Another reason, mainly relevant for one of these two studies, may be due to the fact that the ROR was calculated by the authors of this study using the reported estimates of benefits versus corresponding research costs which usually results in higher ROR estimates, consistent with Alston et al. (2006) observation. The distribution of the rates of returns excluding these two publications is shown in Figure 2. The average ROR for this set of data was 59.17 and around 11% of the studies have an ROR of less than 10% and 18% of the studies have an ROR of less than 15%. There is high dispersion of the observations around the mean for the data set in Figure 1 with standard deviation of 94.54 compared to the data set in Figure 2 with a much smaller standard deviation of 38.91.

Figure 1: Distributions of the Rates of Return to Agricultural R&D for Sorghum and Millet for the entire studies



Average rate of return to agricultural R&D = 84.70673 ***standard deviation =94.54145***

Figure 2: Distributions of Rates of Return to Agricultural R&D for Sorghum and Millet excluding the extreme values



Average rate of return to agricultural R&D = 59.16956 ***standard deviation = 38.90718***

Meta-Analysis of Returns to Research for Sorghum and Millet

Variable descriptions:

The rational of the meta-analyses of the returns to research is to find some explanation for the variation in rates of return to agricultural R&D using the entire case studies on sorghum and millet. For this reason, the dependent variable is the Rate of Return to Agricultural R&D measured in percentage (%) term, which is a continuous variable. We seek to explain the variation in the RORs using variables that describe the studies from multiple dimensions. These variables used for the analyses as outlined in the development of the model are described in the forgoing. Even though we have attempted to form as many explanatory variables as possible, we eliminated potentially useful variables due to lack of sufficient variation in the variables across the studies (e.g. all but one of the studies computed social rates of return) and due to lack of adequate information in the case studies reviewed (e.g. real versus marginal). Under the *characteristics of the rate of return measure (m)* we only included the *ex-ante or ex-post* variable**.** The *ex-ante or ex-post* refers to whether the study was an ex ante (1) or ex post (0). The majority of the studies used average RORs (as opposed to marginal), social RORs (versus private) and hence these two variables were not included due to lack of enough variation in the observations. Another set of explanatory variables is about *analyst characteristics (a):* whether the study was *self-evaluated* or not which refers to whether the study was self evaluated (1) or independent assessment (0); whether the study had been *published* or *not* denoted by (1) if the study was published and (0) if not; a separate group of explanatory variables involved about the *Research Characteristics (r):* under this we have the *Organization/Institution Conducting the Research*. There are three categories of variables dealing with the research organization conducting the impact assessment study: 1) Universities; 2) International Institution and Funding Agencies such as the International Livestock Research Institute (ILRI), FAO, National Agricultural Research Systems (NARS) and 3) Mixed which is a combination of these groups. We had three dummy variables to capture the effects from these categories. Institution type 1: International Institute (1) or not (0); Institution type 2: Mixed (1) or not (0); Institution type 3: University (1) or not (0); in which case the University category was a reference category. The *Scope of research* variable refers mainly to the geographic coverage of the study. These were grouped into 1) sub-national - if the study covers only one region or area or state inside a country; 2) national- if the study was conducted at a national/country level; and 3) multinational- if the study extended to multiple countries such as regional economic blocs (e.g. SADC in the Southern Africa). Three dummy variables were used to capture these effects. Research scope 1: multinational (1) or not (0); Research Scope 2: national (1) or not (2); and Research Scope 3: sub-national (1) or not (0); in which case the Research Scope 3 category was a reference category; the last set of explanatory variables is on the *Evaluation Characteristics (e):* under this we have the *Supply Shift* information variable: in a partial equilibrium analysis framework, the economic surplus analysis due to technological change (in this case introduction of improved varieties/hybrids) is believed to bring about a shift in the supply curve. To accommodate for the variations in the assumptions for the supply shift, we have categorized the observations into parallel supply shift, pivotal supply shift as well as others that do not fall under either of these two categories. The later categories actually do not assume anything; instead conduct the benefit- cost type of analysis. Three dummy variables were formed to capture these effects. Supply shift 1: pivotal (1) or not (0); Supply shift 2: Other (1) or not (0); and Supply shift 3: Parallel (1) or not (0). The supply shift 3 was used as a reference category.

Table 5. Descriptive statistics of the variables used in the regression models

Variables	Mean	Standard deviation	Min	Max
Rate of Return	59.170	38.910	1	134.1
Ex-ante or ex-post	0.268	0.449	0	1
Self evaluation or not	0.262	0.445	0	1
Published or not	0.619	0.492	0	1
Scope of Research				
Multinational	0.050	0.221	0	1
National	0.750	0.439	0	1
Sub national	0.200	0.405	0	1
Institution type				
International Institute	0.310	0.468	0	1
University	0.571	0.501	0	1
Mixed	0.119	0.328	0	1
Supply shift				
Pivotal	0.167	0.377	0	1
Parallel	0.262	0.445	0	1
Other	0.571	0.501	0	1

Table 6. Meta-analysis regression results for sorghum and millet ROR studies

Variables	Coefficients	Standard errors
Ex-ante ex-post	32.192*	17.020
Published or not	-24.397	15.657
Self-evaluation	34.584	30.394
International Institution	-65.508**	24.586
Mixed Institutions	-109.322**	40.950
Multinational Scope	-60.294	40.094
National Scope	-49.925**	20.921
Pivotal Supply Shift	44.389	35.103
Constant	126.932***	22.149
R-squared	0.3211	

* Significant at the 90 percent confidence level; ** significant at the 95 percent confidence level; ***significant at the 99 percent confidence level.
The publish variable was significant at slightly lower than 90 percent confidence level (88%).

Empirical Results

Rates of return analysis for sorghum and millet

The empirical results for the regression analysis are shown on table 6. The regression model with an adjusted R-squared of 0.32 is able to explain almost one third of the variation in the data. Based on the regressions results, the following general observations can be made:

Higher rates of return are indicated when the rate of return is:

- ex ante (versus ex post)
- the research evaluation is a self-evaluation (as opposed to an independent evaluation)
- pivotal supply shift (versus parallel or other supply shift assumptions)

Lower rates of return are indicated when:

- the evaluation is published in a refereed journal compared with less formal outlets

- when the evaluation exercise is conducted by an international institution (as opposed to University)
- when the evaluation exercise is conducted by a mixed institution (as opposed to University)
- if the scope of research evaluation has a multinational coverage (versus sub national coverage)
- if the scope of research evaluation has a national/country level coverage (versus sub national coverage)

Following is a closer investigation of the effect of the variables used in the regression analyses. The variables with positive estimated coefficient indicating a positive effect to the estimated rates of return are presented first followed by those variables with negative impact on the estimated rates of return.

Ex-ante or ex-post*:* for the studies reviewed, this variable was statistically significant at 90% confidence level. The ex-ante studies have in general higher rates of return compared to ex-post studies. This finding is contrary to the Alston et al. (2000) meta-analysis results. Using a larger set of data across an extensive coverage of commodities and technologies, Alston et al. (2000) findings with respect to this variable conforms with the widely asserted explanation of “cherry picking” of studies which favors higher rates of return for ex-post type of studies. A possible explanation for the findings of the present study may be associated with the particular regions of studies for sorghum and millet. The majority of the studies being ex-post type are conducted in the Sub-Saharan Africa. Evaluations of returns to research in such areas not only reflect the technology introduction, but also the cumulative effect of the market/economic conditions and policy frameworks, which may in general reduce the potential economic impact of the introduced technology.

Self-evaluation or not: higher returns to research are associated when the evaluation is self-evaluated rather than independent analysis, in contrast to the Alston et al. (2000) findings. However this variable was not statistically significant.

Supply shift: according to the regression results, studies that used pivotal supply shift assumption have generally reported higher rates of return compared to other supply shift assumptions, although the coefficient for this variable was not statistically significant. The sign of this variable is in agreement with Alston et al. (2000) findings.

Evaluation is published or not: rate of return studies that were published in refereed journals have on average lower rates of return compared to less formal outlets , in agreement to the Alston et al.(2000) findings, although this variable was not statistically significant. Alston et al. (2000) explained this result may be due to the fact that a published result may have been more heavily scrutinized leading to lower rates of return.

Institution type: lower rates of return were reported when the institutions conducting the evaluation exercise were either an international institution or mixed institution as opposed to a University, both of these being statistically significant at the 95% confidence level. In comparison, mixed institutions have much lower rates of return indicated by the more negative coefficient for this variable.

Scope of research**:** this variable refers to the geographic coverage of the study. Compared to the reference category of sub-national studies (if the study covers only one region or area or state inside a country), both national (nationwide) and multinational studies have lower rates of return. The national level variable is statistically significant at 95% percent confidence level; where as the multinational level is not statistically significant.

Excluding the variables that are not statistically significant, we may interpret the constant coefficient as an ex-post research evaluation conducted at a sub-national level (certain area or region within a country) by a University research evaluator will have an average rate of return of 126%. We may also infer that all else kept constant, impact assessment conducted at a national level produce lower rates of return (ROR). Evaluations conducted by a team from both mixed institutions and international institutions have yielded lower rates of return compared to University evaluators, all else kept constant.

Rates of return analysis for sorghum

In most cases sorghum and millet are researched and funded together, especially in such international research initiatives as INTSORMIL or ICRISAT. We have seen earlier that close to three quarter of the studies reviewed focused only on sorghum (Table 4). Controlling for the type of commodity, the meta-analyses for returns to research were conducted solely for sorghum. There were not enough observations to conduct similar analyses for millet studies only. The *scope of research* referring to the geographic coverage of the study used to describe the *research Characteristics (r)* variables was not used here because there was not enough variation in this variable across all the observations. Furthermore, only the mixed institution variable was included in the regression analysis due to high multi collinearity between this variable and the international institution variable. The regressions results for the rates of return studies on sorghum are reported on table 7. The adjusted R-squared of 0.20 would indicate that the model is able to explain 20% of the variation in the data.

Table 7. Meta-analysis regression results for sorghum ROR studies

Variables	Coefficients	Standard errors
Ex-ante ex-post	50.479**	20.340
Published or not	-32.698*	16.944
Self-evaluation	34.788*	18.706
Mixed Institutions	-78.500*	40.631
Pivotal supply shift	53.905	36.481
Constant	75.793***	9.313
R-squared	0.2095	

* Significant at the 90 percent confidence level; ** significant at the 95 percent confidence level; ***significant at the 99 percent confidence level.

The supply shift assumption variable was significant at a lower than 90 percent confidence level (85%).

All except the *pivotal supply shift* variable explain the variation in rates of return results statistically significantly at least at the 90% significance level. After controlling for the commodity of analyses, both variables that capture the analyst characteristics (*publish-or-not* and *self evaluated-or-not*) turned out to be statistically significant. The signs on all of the explanatory variables used in this regression analyses remained the same as in the previous regressions using the whole set of data.

Using the statistically significant explanatory variables, an unpublished independent (as opposed to self assessment) ex-post evaluation conducted by a university evaluator on average had an annual rate of return of 76%. Keeping everything else constant, the rates of return are lower for studies that were published. Compared to University, mixed institution evaluators had lower rates of return as well. However, both ex-ante and self evaluated studies showed higher rates of return, all other variables kept unchanged.

Bootstrap Inferences

The regression analyses inferences made in the previous sections are based on small sample /asymptotic properties of the statistics of interest. Often times the distribution of a test statistic under the null hypothesis may or may not be known precisely. Horowitz (2001) explains that reliable statistical inference can be done using the bootstrap technique. The bootstrap is a method for estimating the distribution of an estimator or test statistic by re-sampling one's data or a model estimated from the data. It amounts to treating the data as if they were the population for the purpose of evaluating the distribution of interest (Horowitz, 2001). MacKinnon (2006) discusses that there are theoretical reasons to believe that bootstrap tests often work better than asymptotic tests. Bootstrap methods involve estimating a model many times using simulated data. Quantities computed from the simulated data are then used to make inferences from the actual data. What determines how reliably a bootstrap test performs is how well the bootstrap Data Generating Process (DGP) mimics the features of the true DGP that matter for the distribution of the test statistic(MacKinnon, 2006). The procedure for generating the bootstrap samples, which always involves a random number generator, is called a bootstrap data generating process, or bootstrap DGP. In a testing situation, the bootstrap can provide more reliable inference than other conventional methods (Davidson, 2007).

Bootstrapped regressions

Empirical results from the bootstrap experiments are shown in tables 8 and 9. The inference results after the bootstrap simulations are similar for most of the variables. Whether the rate of return study was published or not and whether it was self/independently-evaluated do not statistically significantly affect the estimation on rate of return results. The statistical significance of both the *Scope of research* in terms of the geographic coverage of the study and the *Supply Shift* variables improved very well after the bootstrap experiments. The statistically significant coefficient on the multinational scope variable at this time would indicate that rate of return studies covering multiple countries or regions have a negative impact on the estimate compared to the default group of sub-national research coverage.

Table 8. Meta-analysis regression results for sorghum and millet studies (bootstrapped with 10212 replications)

Variables	Coefficients	Bootstrap Standard errors
Ex-ante ex-post	32.191**	14.903
Published or not	-24.397	15.176
Self-evaluation	34.584	23.595
International Institution	-65.508***	15.046
Mixed Institutions	-109.322***	27.969
Multinational Scope	-60.294*	34.341
National Scope	-49.925**	22.249
Pivotal Supply Shift	44.389***	10.312
Constant	126.932***	24.623
R-squared	0.3211	

* Significant at the 90 percent confidence level; ** significant at the 95 percent confidence level; ***significant at the 99 percent confidence level.

Table 9. Meta-analysis regression results for sorghum (bootstrapped with 10945 replications)

Variables	Coefficients	Bootstrap Standard errors
Ex-ante ex-post	50.480***	10.604
Published or not	-32.698***	12.525
Self-evaluation	34.788***	9.122
Mixed Institutions	-78.500***	4.971
Pivotal supply shift	53.905***	6.017
Constant	75.793***	12.959
R-squared	0.2095	

* Significant at the 90 percent confidence level; ** significant at the 95 percent confidence level; ***significant at the 99 percent confidence level.

It is very interesting to note that after controlling for the commodity of analysis, sorghum in this case, the statistical significance of all the variables of interest have improved a great deal. Even the pivotal supply shift variable was strongly significant at the 99% confidence level.

Conclusions/Recommendation

As a result of the offsetting effect of a rise in productivity and decline in harvested area, the world sorghum production (tonnes) has been on a horizontal trend. The combined effect of a decline in area harvested and a rise in yield productivity have resulted in an overall increase in world millet production (tonnes) trend.

During the last three decades, significant numbers of breeding lines, parental stocks, germplasm and cultivars have been released through INTSORMIL/host countries collaboration around the world. Some of the remarkable breeding success stories include the release of the first hybrid sorghum Hageen Dura (HD-1) and *Striga* tolerant varieties in Sudan; the introduction and release of Sureno sorghum variety in Honduras ; and numerous other releases in various other African and Latin American countries such as Mali (Malisor lines with excellent head bug resistance, N'Tenimissa-tan plant guinea type cultivars), Niger (high yielding varieties as well as drought resistant hybrids), Nigeria (LCICMH-I -a pearl millet hybrid with early maturing characteristic), Zambia (improved varieties such as Kuyuma and Sima and hybrids such as MMSH-928 for drought prone areas , MMSH-1324 for resistant to most diseases, and MMSH-1256 widely adapted to most of the country) and Ethiopia (Striga resistant varieties such as Gubiye, Abshir and Brhan), Columbia (two varieties, Sorgo Real 40 and Sorgo Real 60 that are tolerant to Al and salt).

On a global coverage, the average rate of return to sorghum and millet agricultural R&D investments is about 60 percent per year which is in the range of the average rate of return estimated for agricultural R&D investments. Despite the positive and promising returns to investment in sorghum and millet researches, there appears to be limited economic analysis done in such endeavors. It is important to increase the impact assessment studies to provide empirical support to investments in sorghum and millet improvement technologies. INTSORMIL host countries have benefited from a significant amount of cultivar releases over the last three decades. Based on INTSORMIL reports and successful releases as well as potential adoptions, more impact assessment type of studies should be done in general in Asia (India) and the United States as well. Other countries for that deserve economic impact assessment are: Honduras (for example the variety Sureno), Columbia (aluminum/salt tolerant varieties), Mali, Niger and Zambia (all with multiple cultivars) particularly based on the significant amount of varietal releases in record during the life span of INTSORMIL. Analysis of dynamics of the data on the area harvested during INTSORMIL’s lifespan would also show that Nigeria, Niger- for example SEPON82 is the most adapted cultivar in Southern Maradi region of Niger[7] -, Mali, Senegal, Ghana, Burkina Faso, Ethiopia and Uganda have seen an increase in the area harvested (ha) to Sorghum that lends support to the need to undertake impact assessment studies.

So many reports reveal that quite significant amount of releases are already out there for farmers to use. In spite of the successful research and development progress shown through INTSORMIL in

[7] http://intsormil.org/SMNewsletterArchive/2011AugustINTSORMIL_Newsletter.pdf

particular and local and international research centers in general, nonetheless, the lack of functional technology transfer institutions continue to pose significant impediments for the overall solutions to development in agriculture.

In general, it is observed that the majority of the economic impact assessment studies were evaluations of past R&D investments (ex-post type analyses) and even more so in the Sub-Saharan Africa countries. Even though, the amount of such ex-post studies is by no means enough, it is essential to consider that adequate economic impact assessment studies (ex-ante type) be undertaken to help aid in the crafting of effective technology introductions and policy designs.

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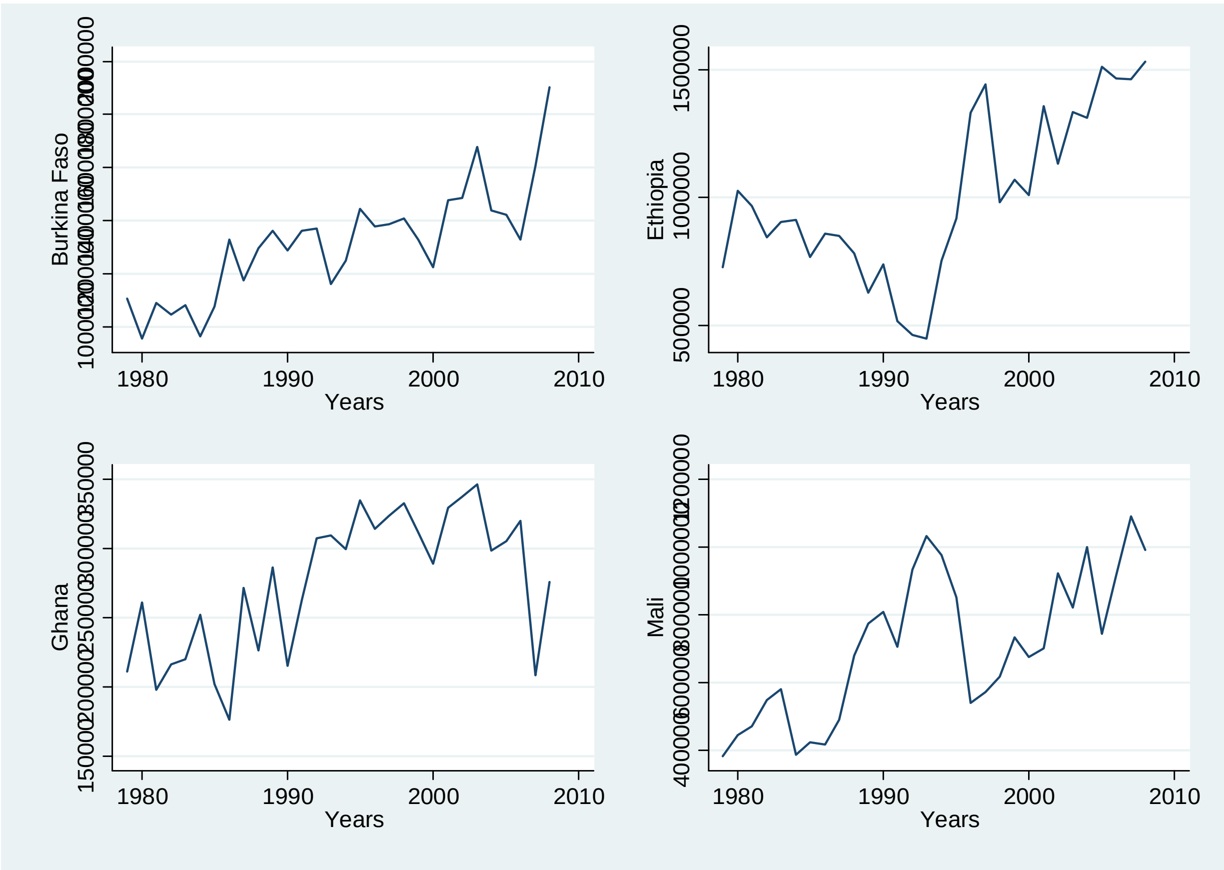
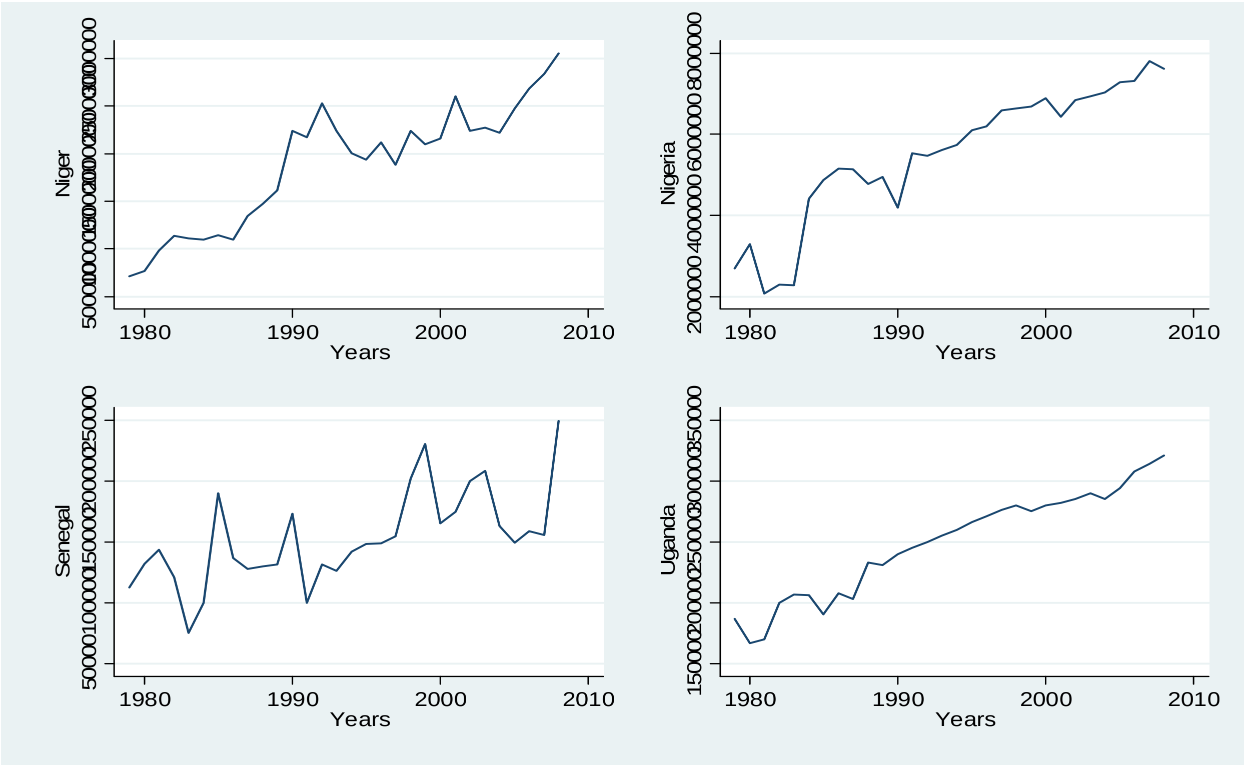
Assessment of the Impact of INTSORMIL and Peanut CRSPs Technology in Mali

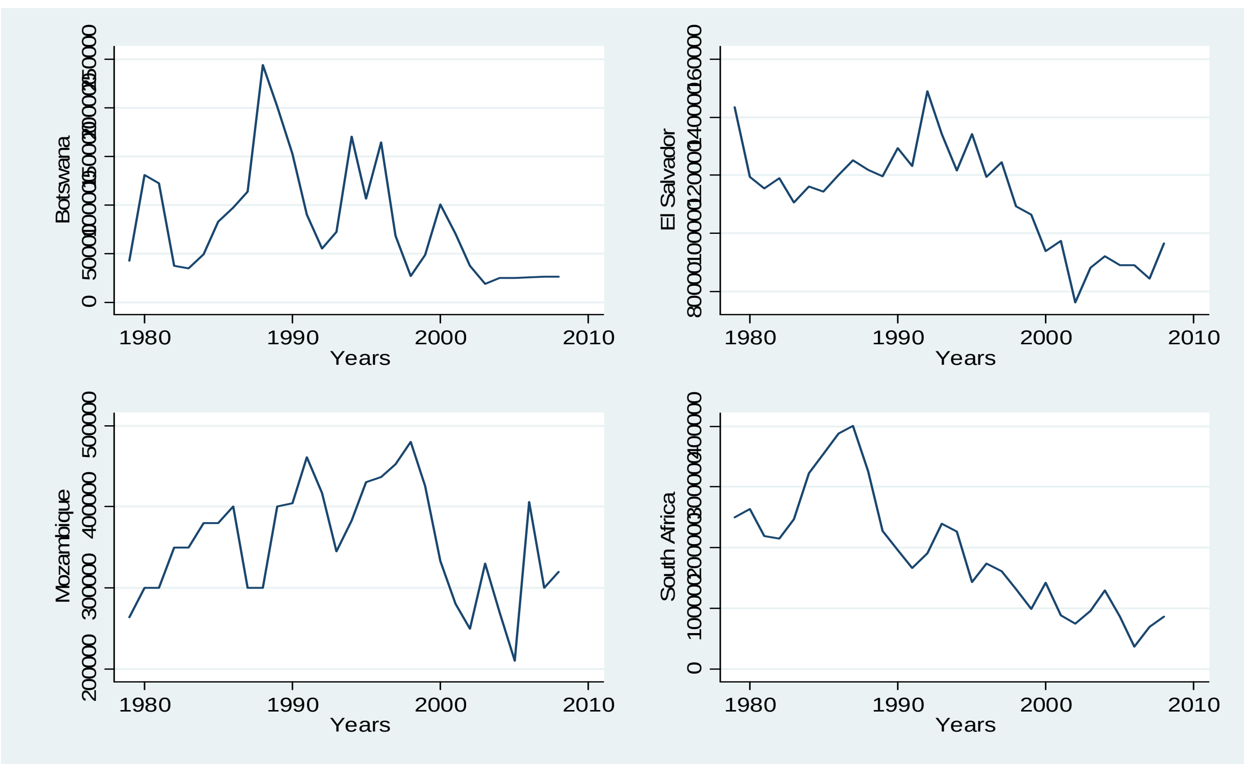
Appendix 1: Sorghum and Millet Production Patters

Countries with increasing Sorghum area harvested in hectares (ha)

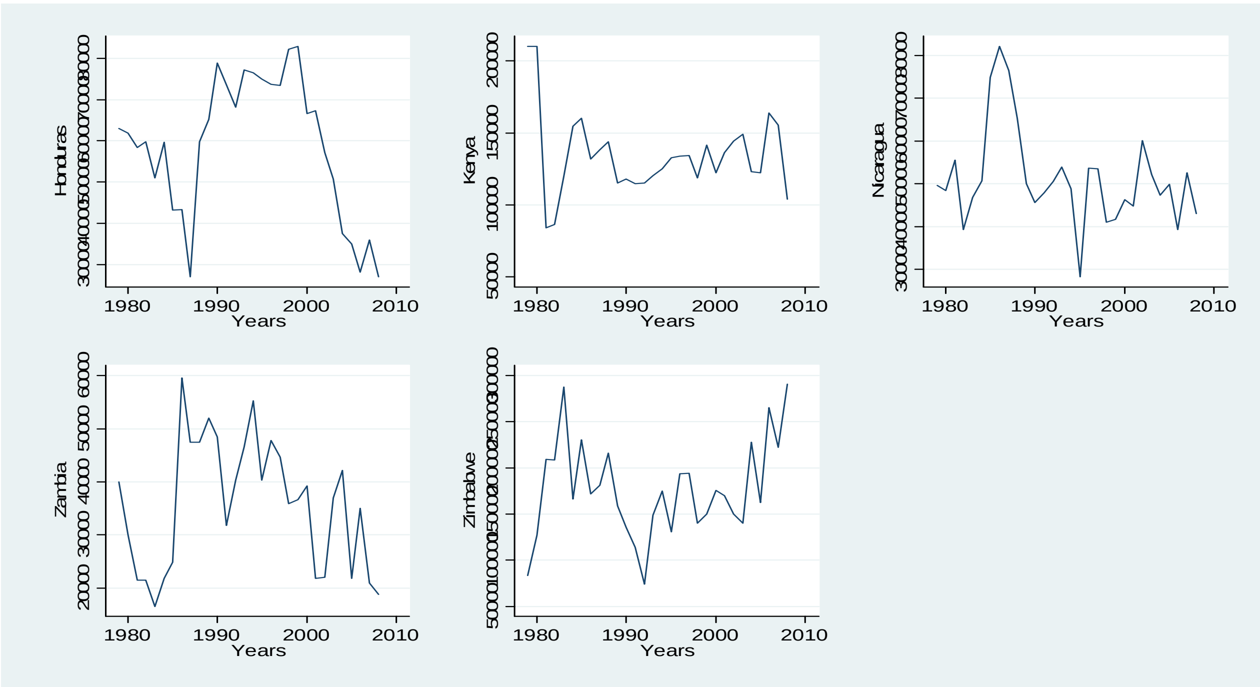




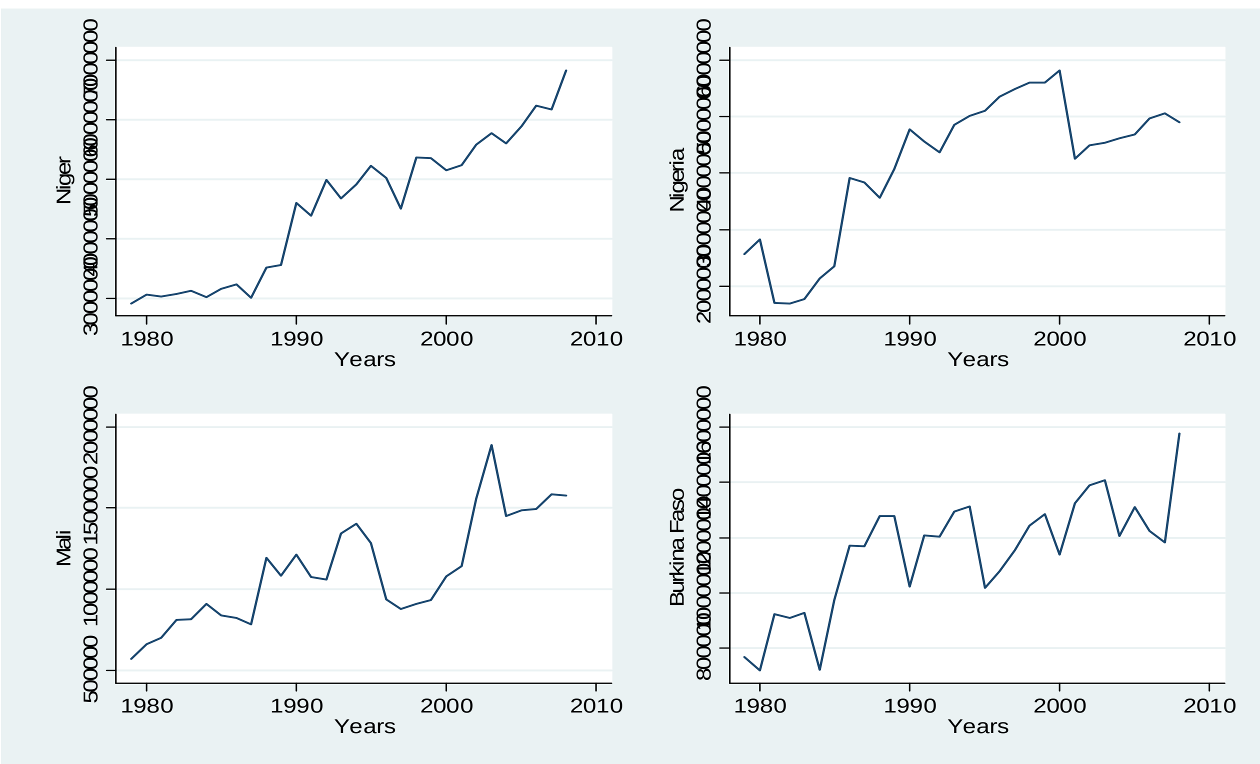
Countries with decreasing Sorghum area harvested in hectares (ha)

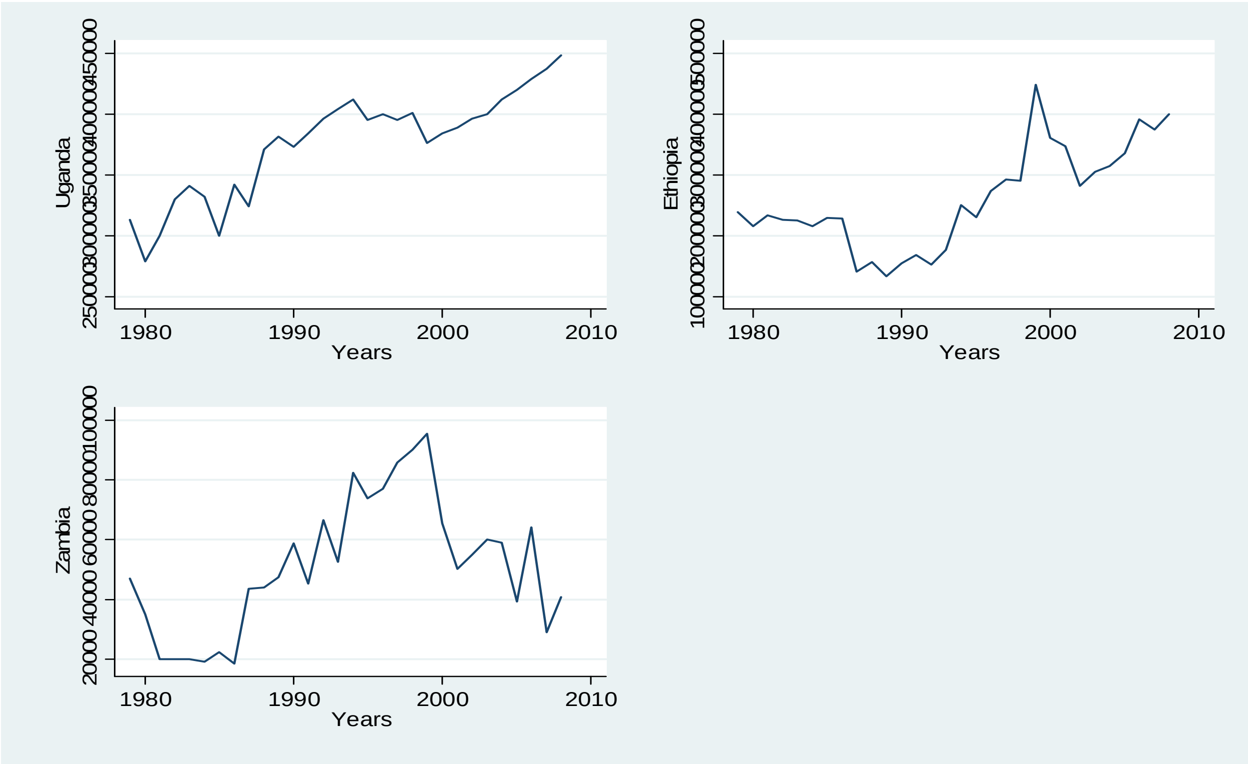


Countries with Neither increasing nor decreasing Sorghum area harvested (ha)

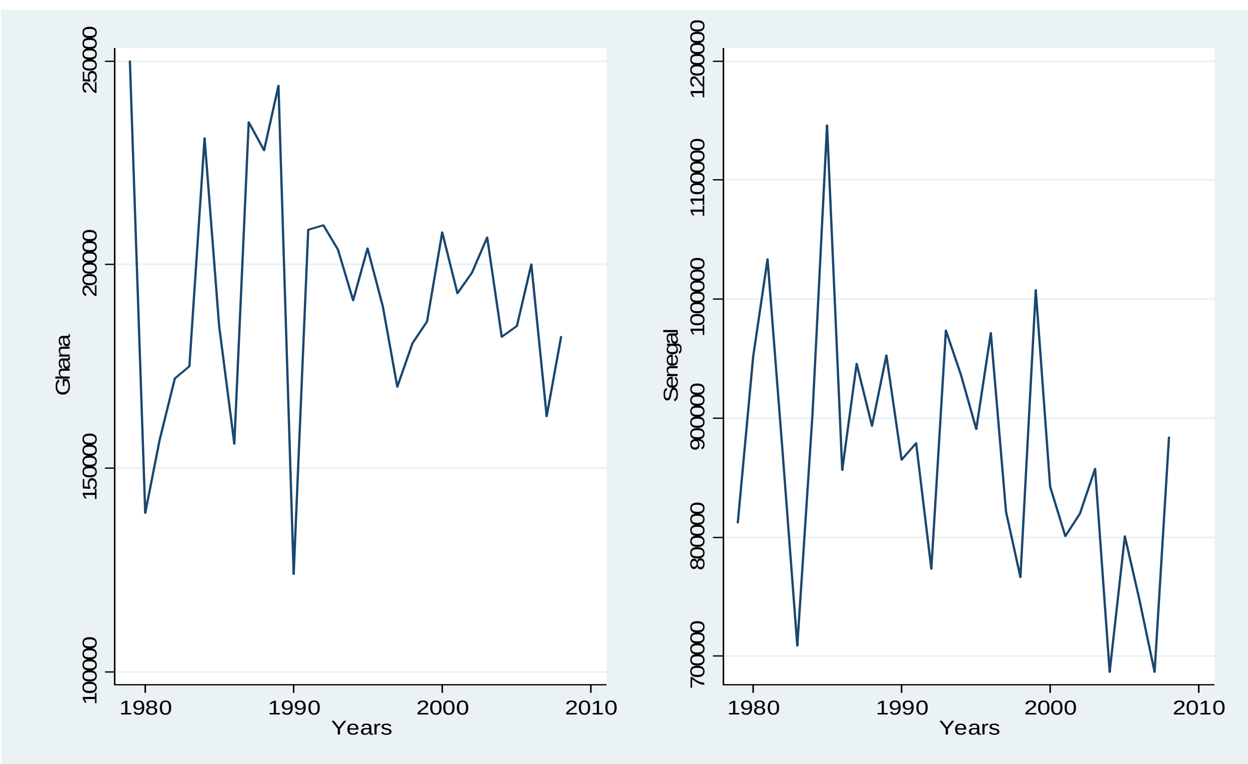


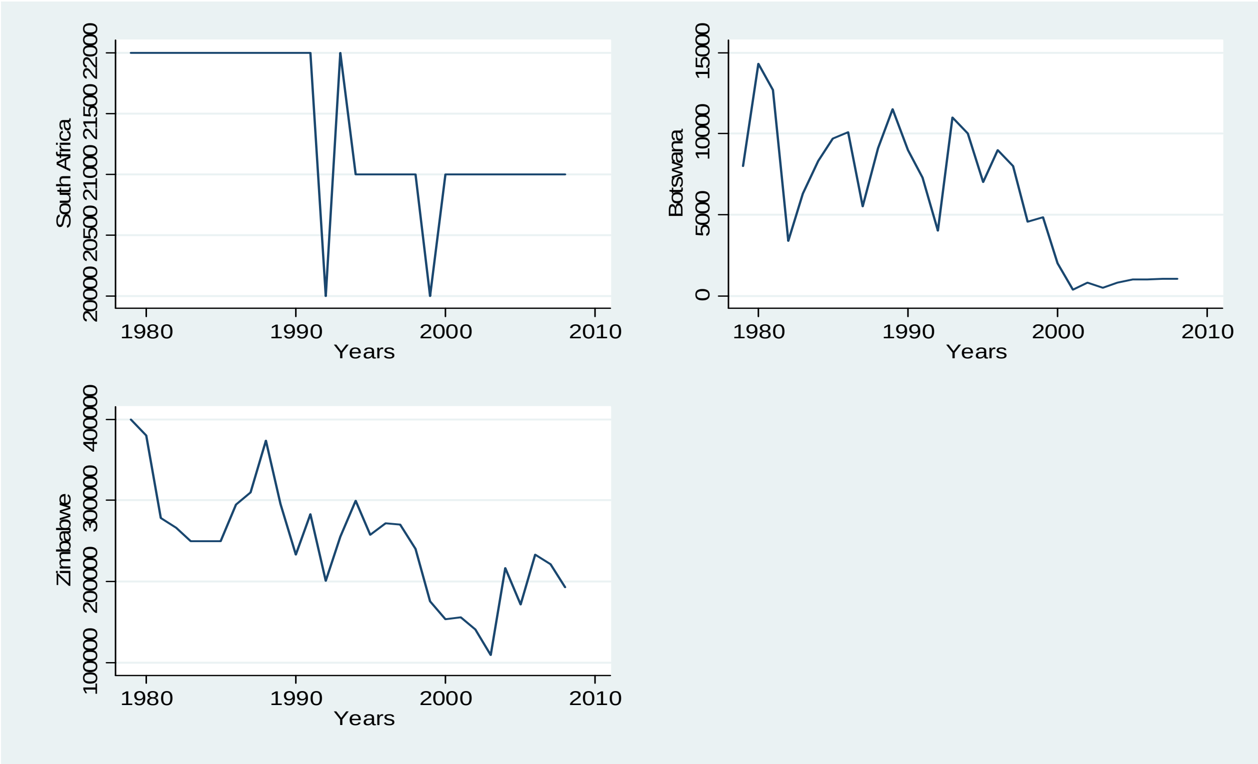
Countries with increasing Millet area harvested in hectares (ha)



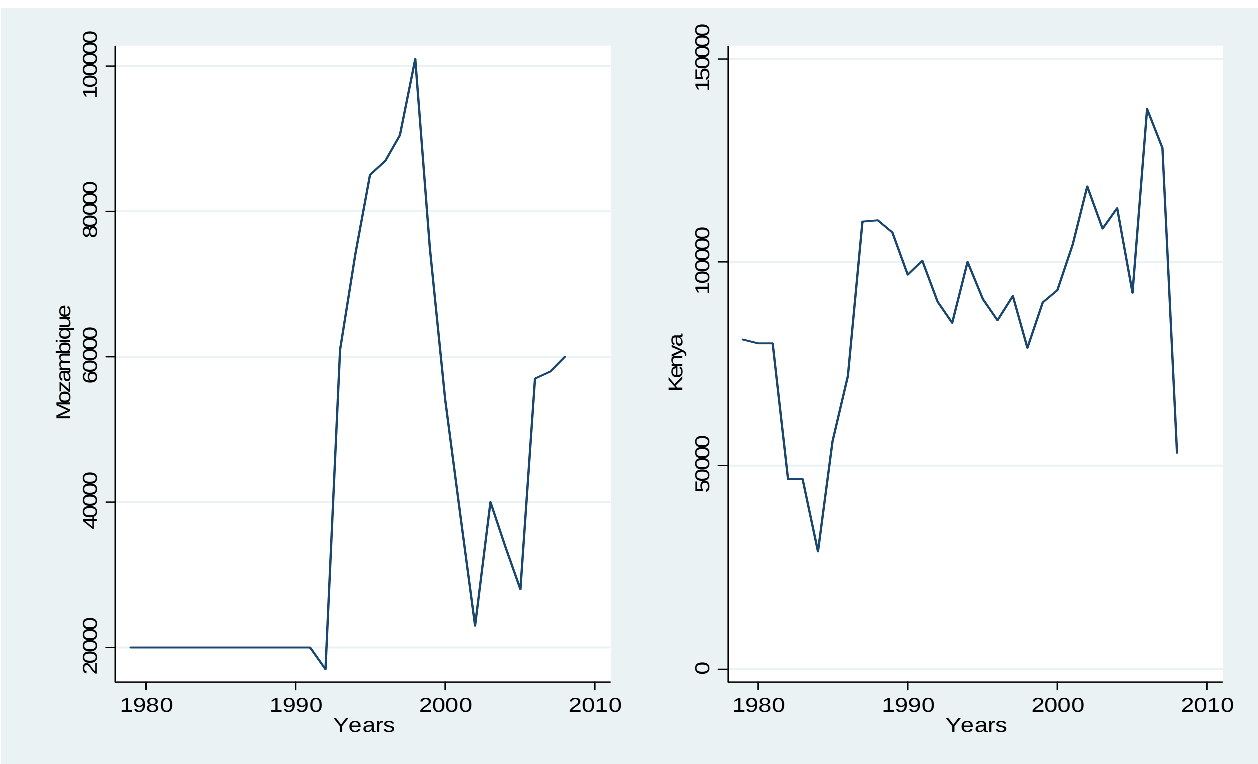


Countries with decreasing Millet area harvested in hectares (ha)

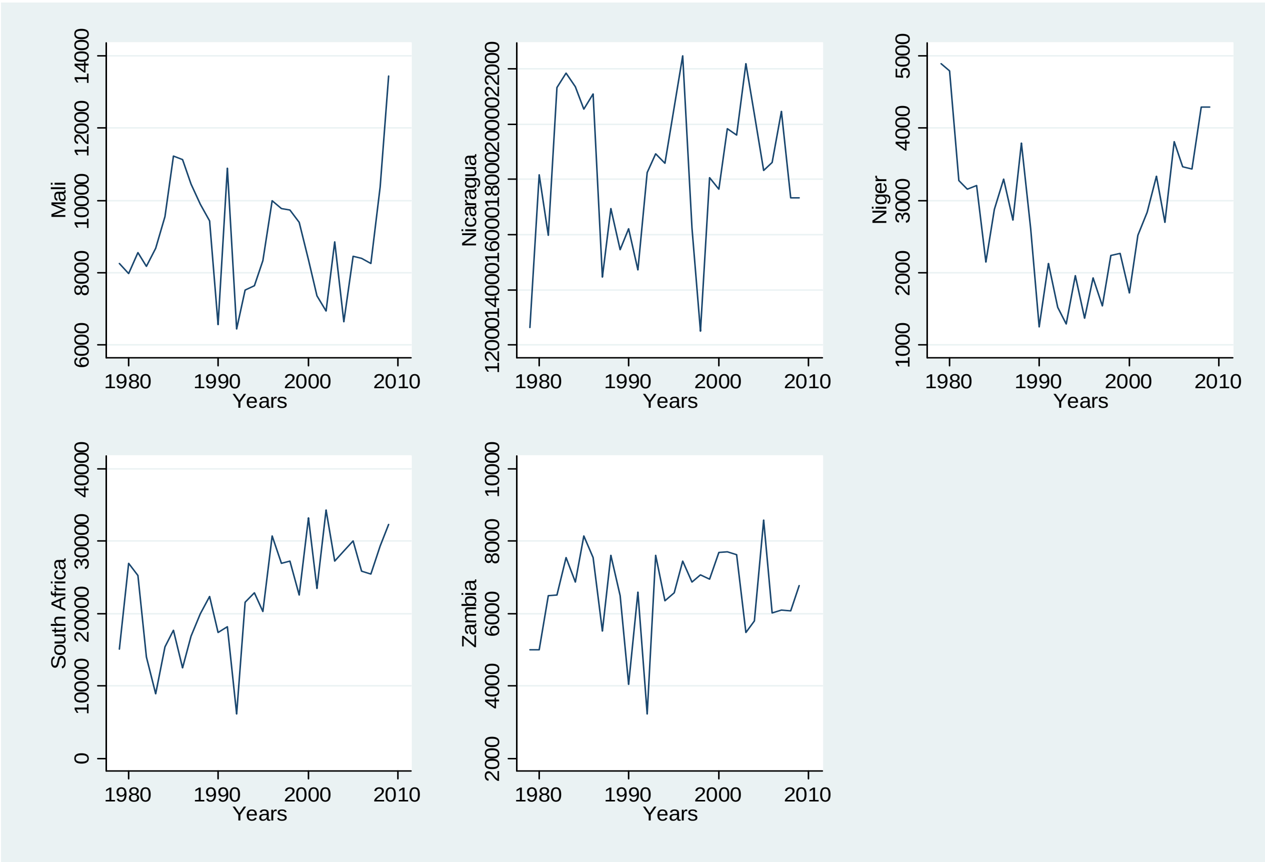




Countries with neither increasing nor decreasing Millet area harvested in hectares (ha)



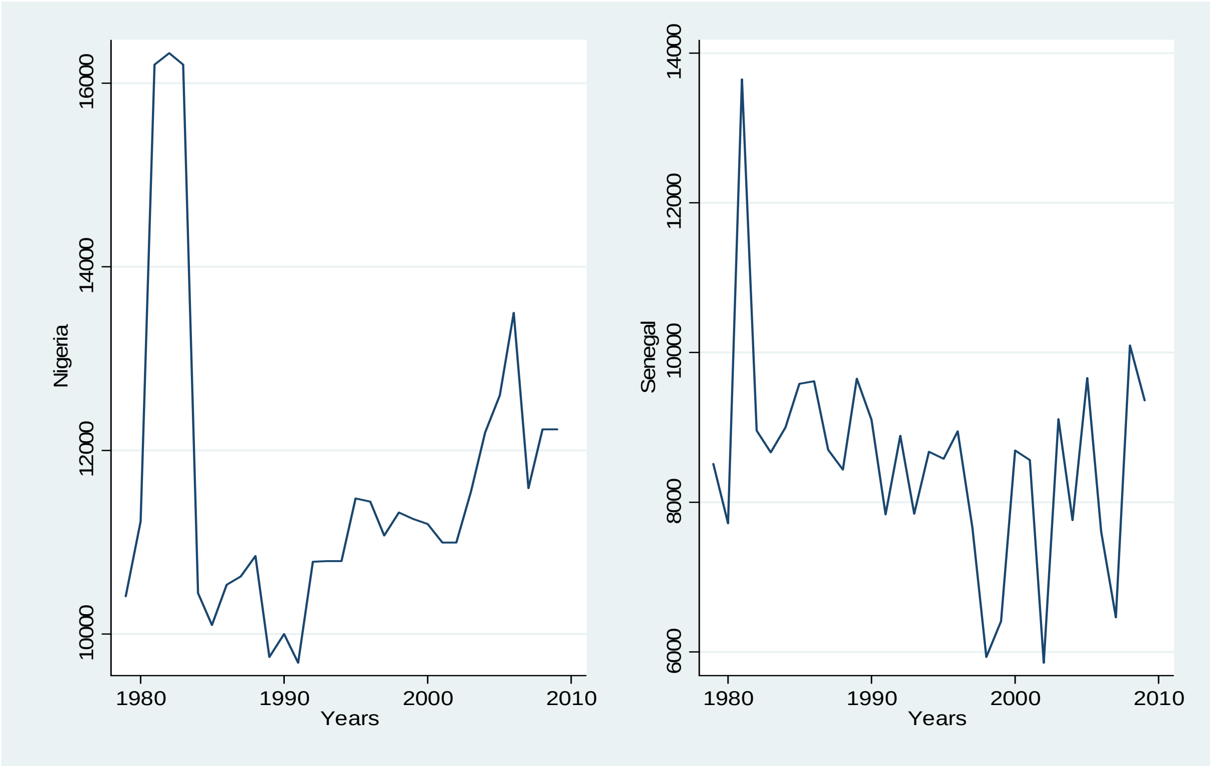
Countries with Increasing Sorghum yield (Kg/Ha)



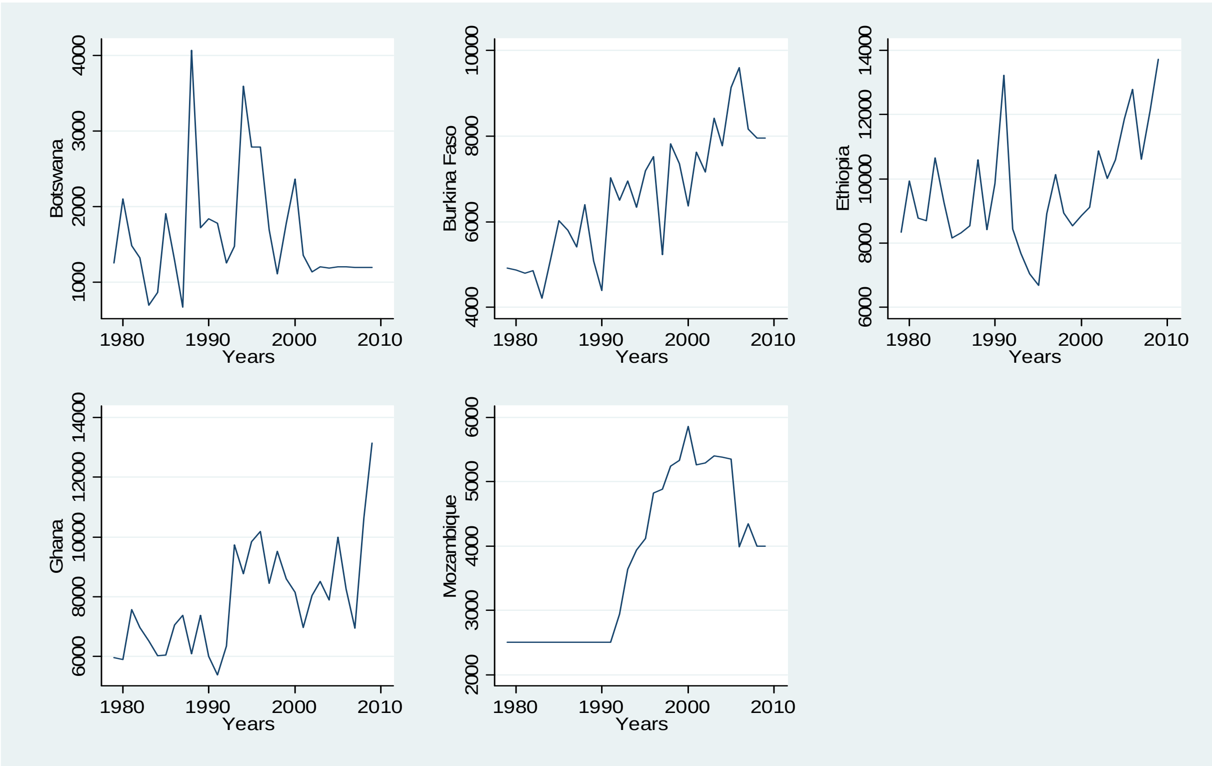
Mali
Nicaragua
Niger
South Africa
Zambia
Years
1980
1990
2000
2010

Countries with Decreasing Sorghum yield per ha

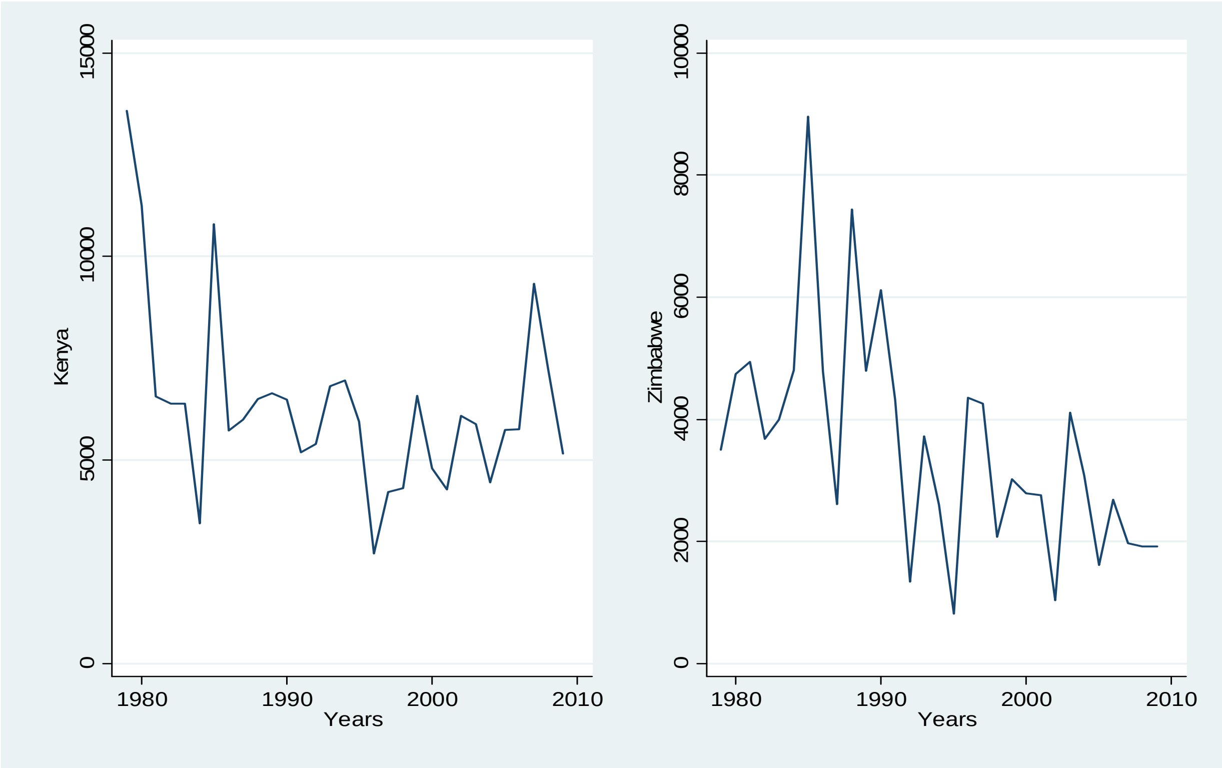
Countries with neither increasing nor decreasing Sorghum yield per hectare



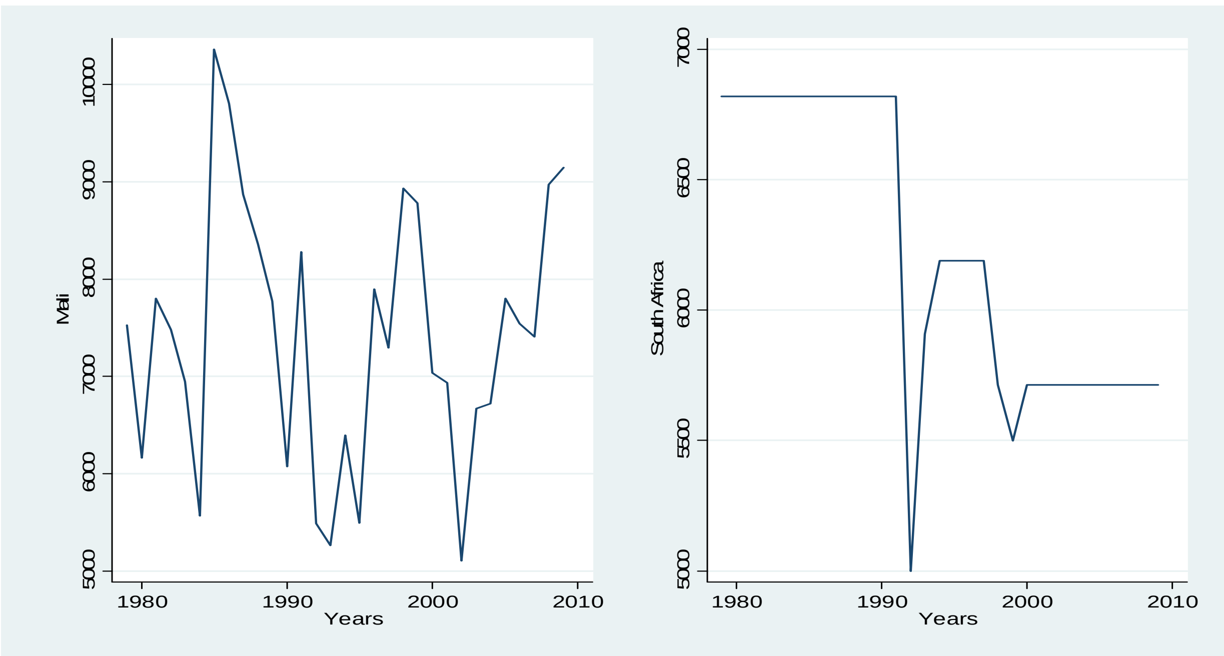
Countries with Increasing Millet Yield per Hectare



Countries with Decreasing Millet Yield per Hectare



Countries with neither increasing nor Decreasing Millet Yield per Hectare

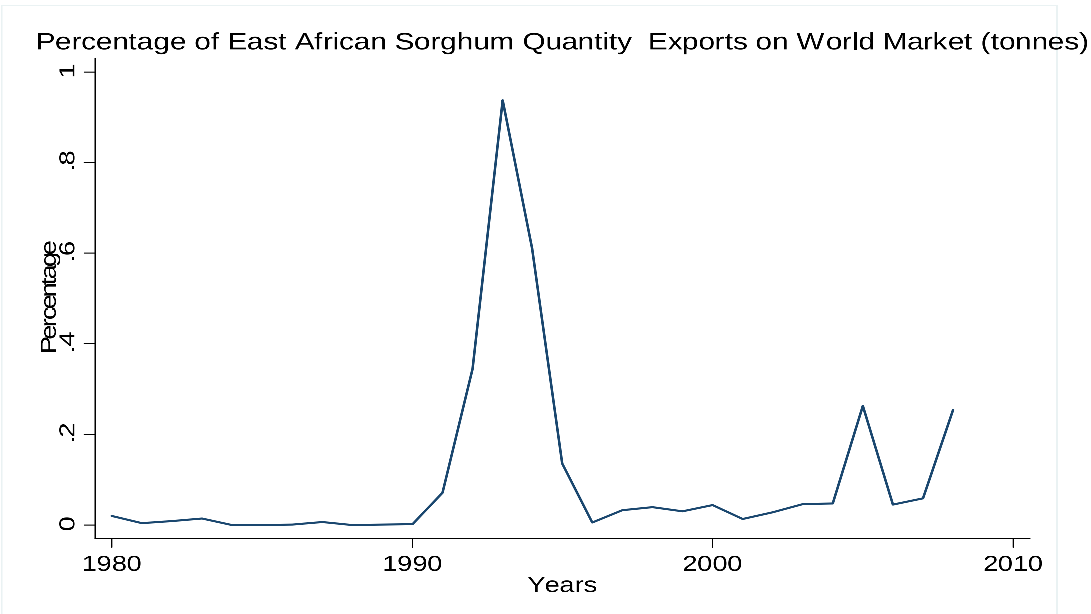


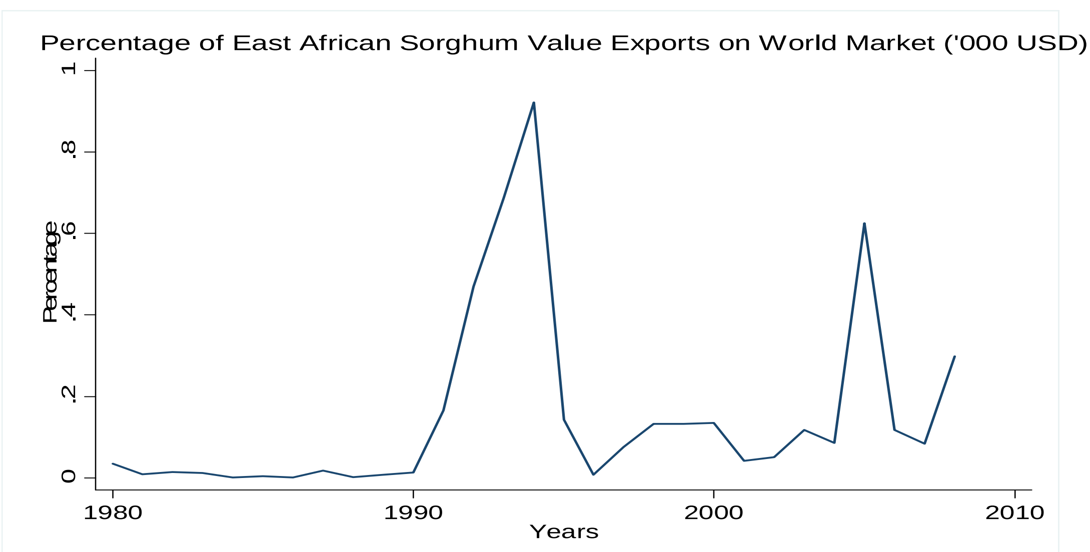
Appendix 2: Quantity and Value of Sorghum and Millet traded from the different regions covered by INSORMIL

Sorghum Traded from the different regions covered by INSORMIL

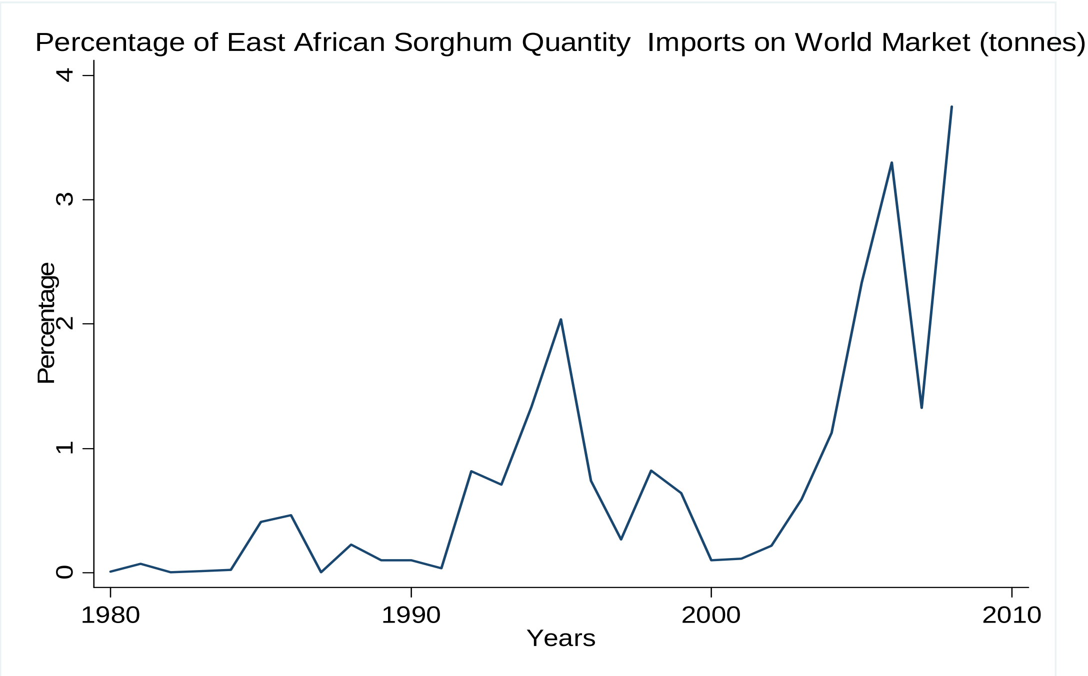
East Africa

Exports

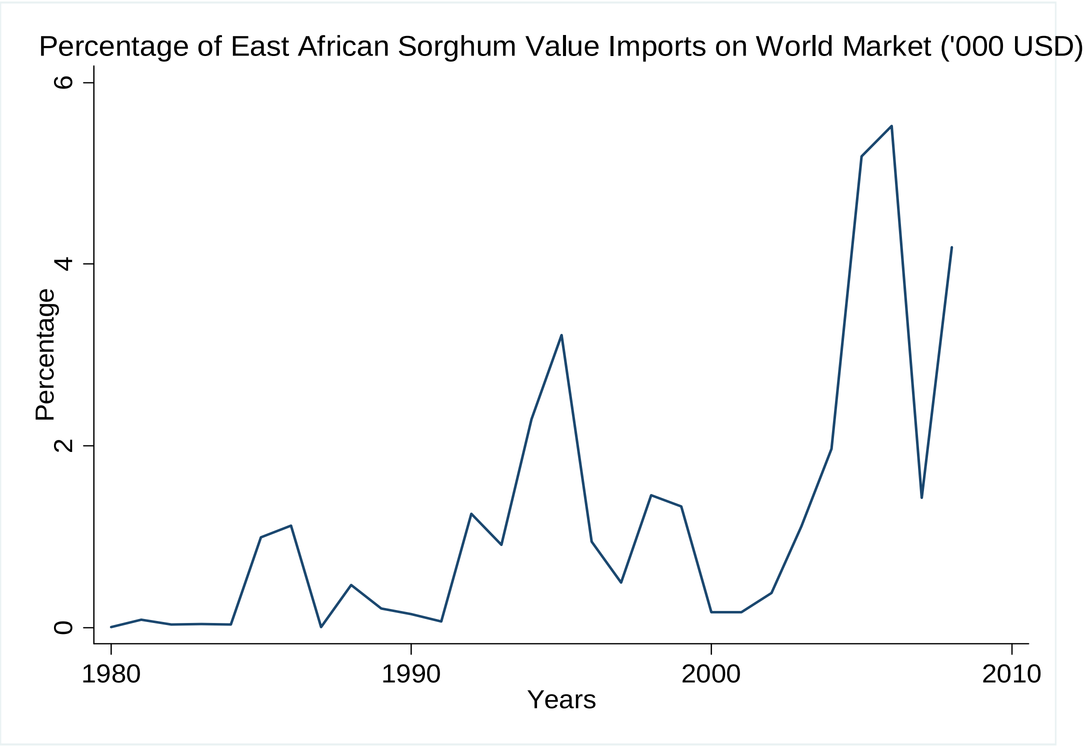




Imports



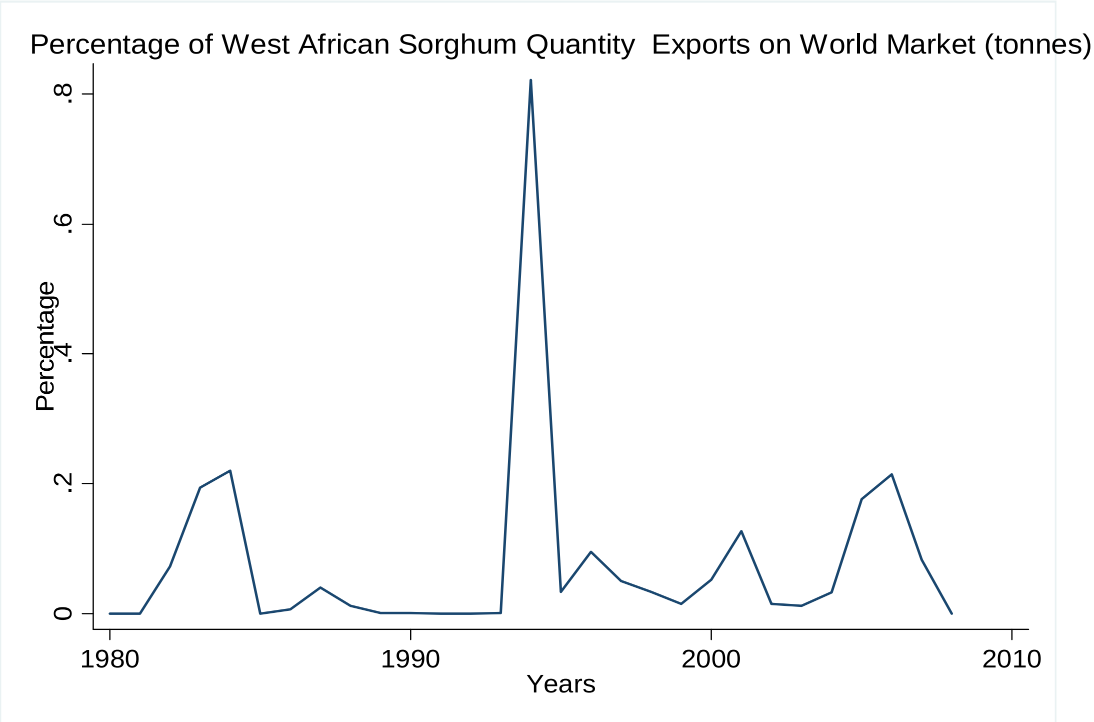
Percentage of East African Sorghum Quantity Imports on World Market (tonnes)
Percentage
0
1
2
3
4
1980
1990
2000
2010
Years

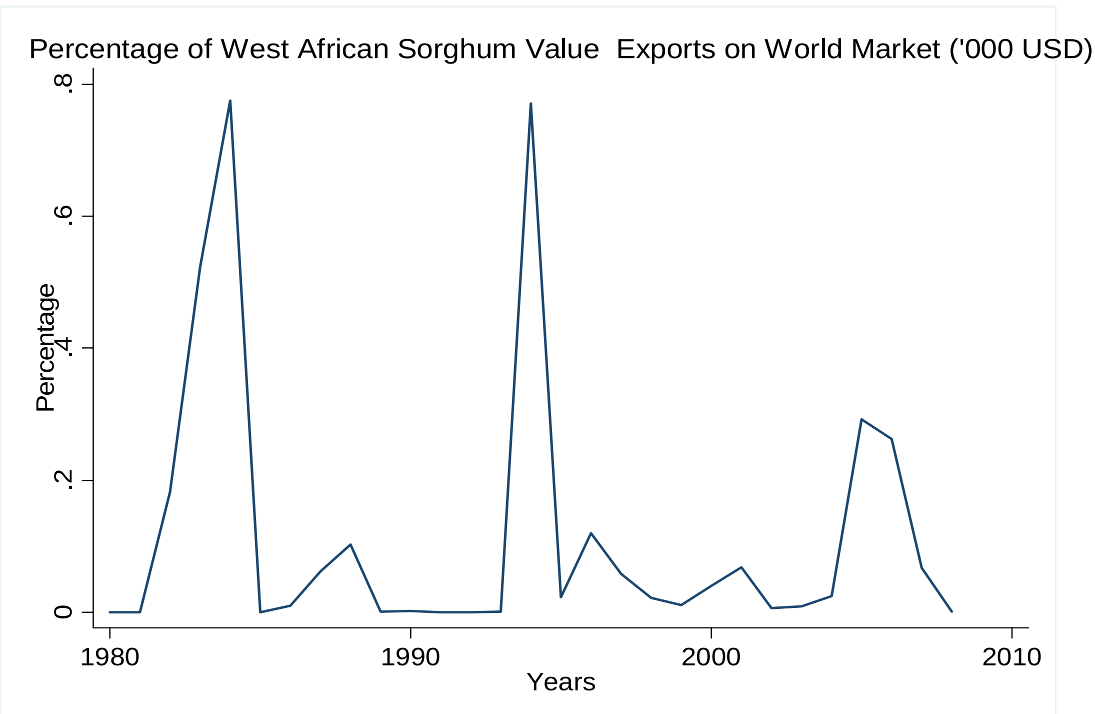


Percentage of East African Sorghum Value Imports on World Market ('000 USD)
Percentage
0
2
4
6
1980
1990
2000
2010
Years

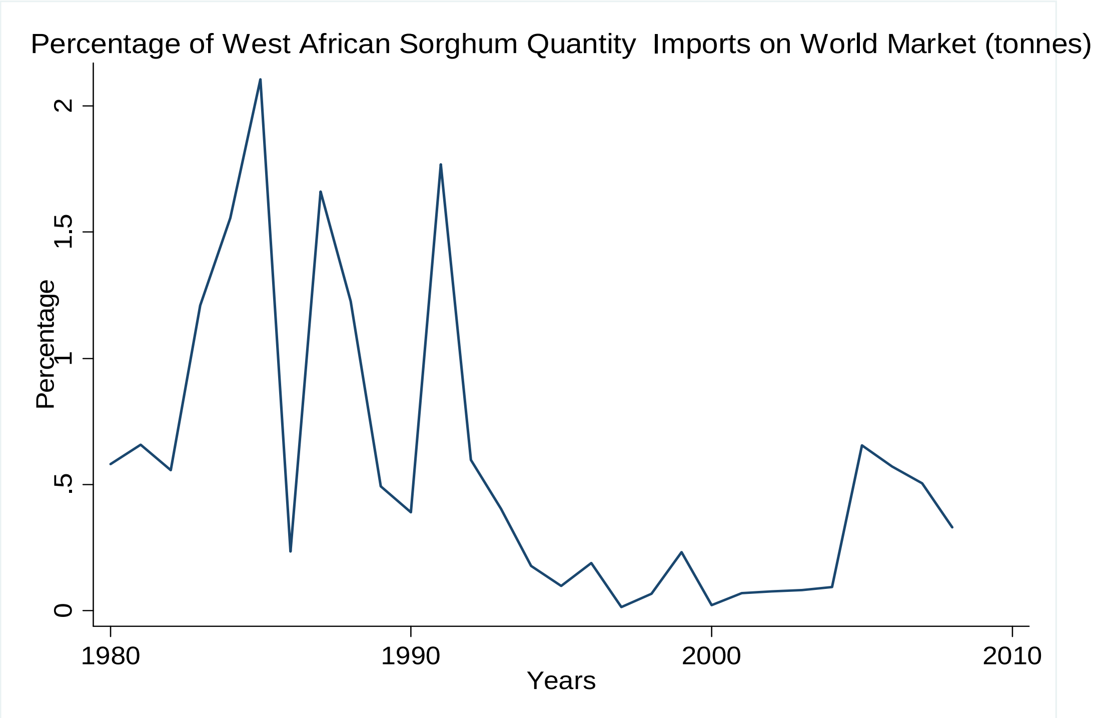
West Africa

Exports

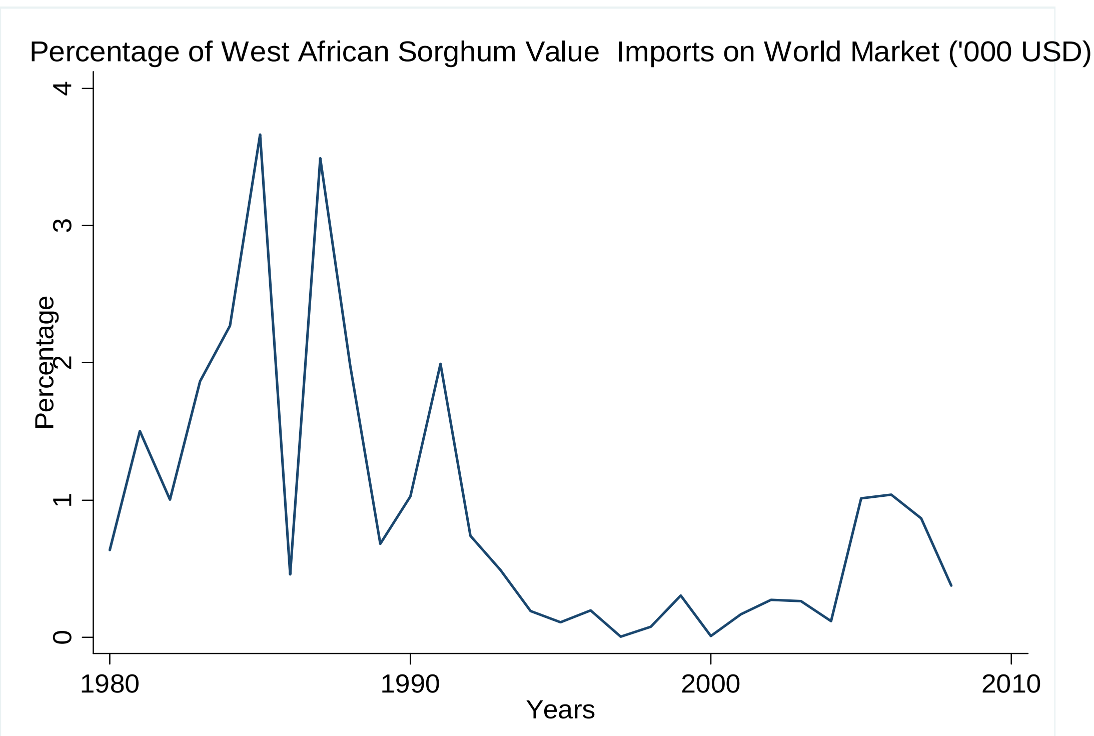




Imports



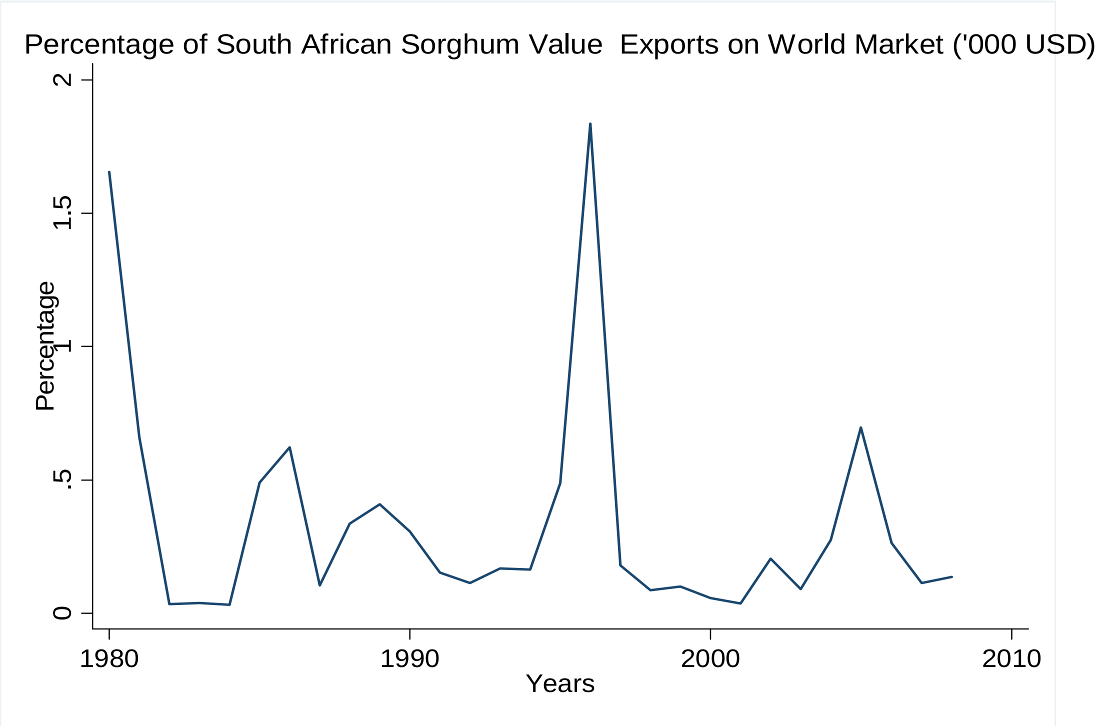
Percentage of West African Sorghum Quantity Imports on World Market (tonnes)
Percentage
0
.5
1
1.5
2
1980
1990
2000
2010
Years



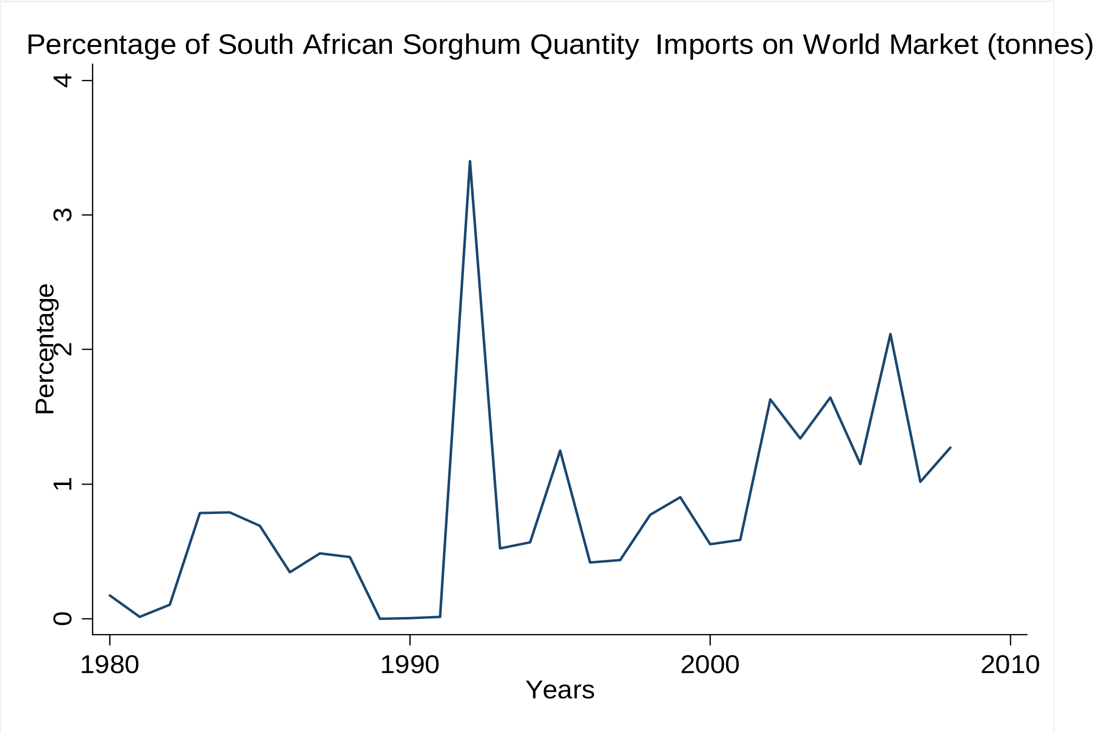
Percentage of West African Sorghum Value Imports on World Market ('000 USD)
Percentage
0
1
2
3
4
1980
1990
2000
2010
Years

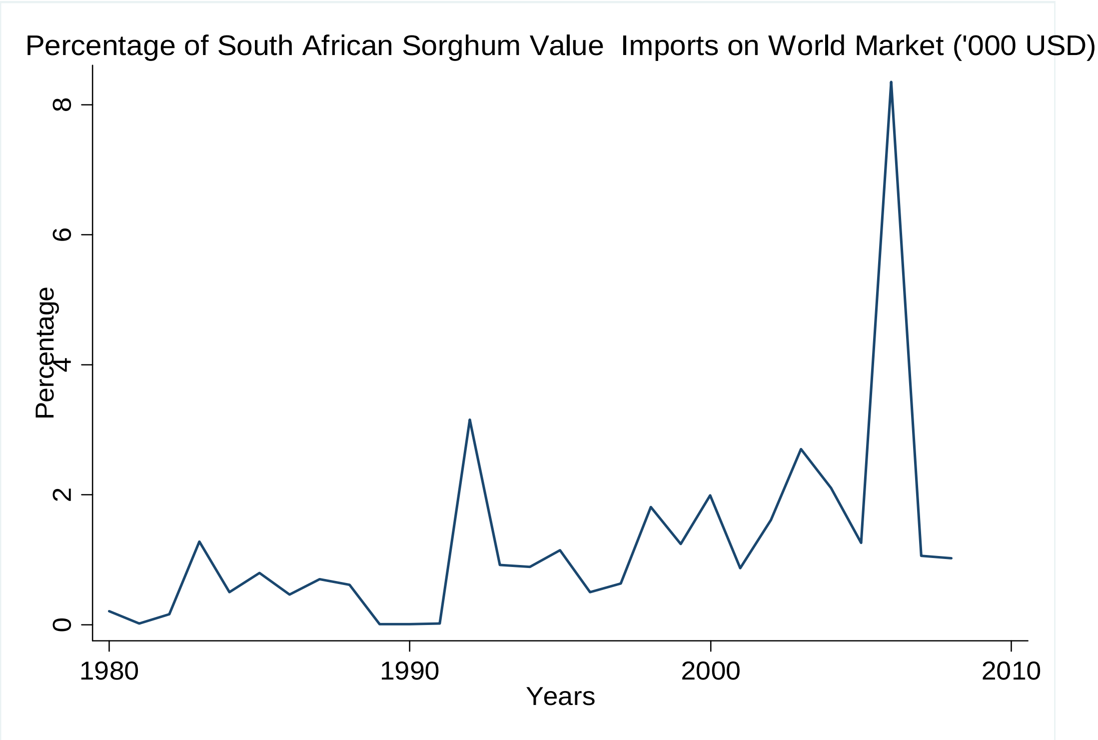
Southern Africa

Exports



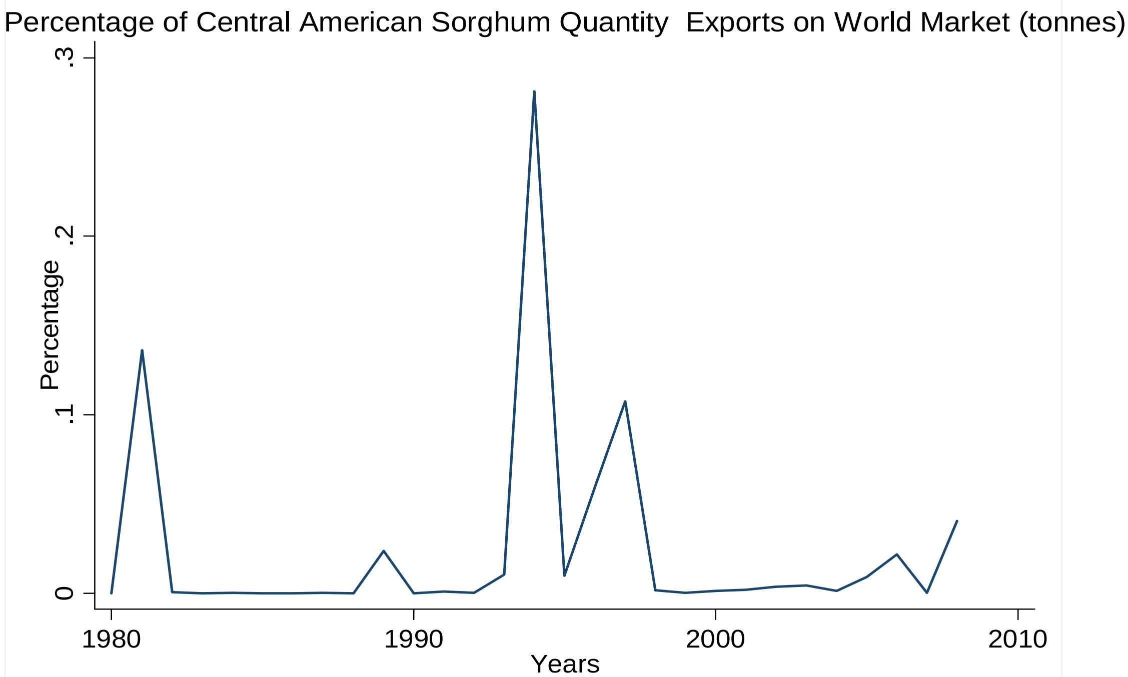
Imports

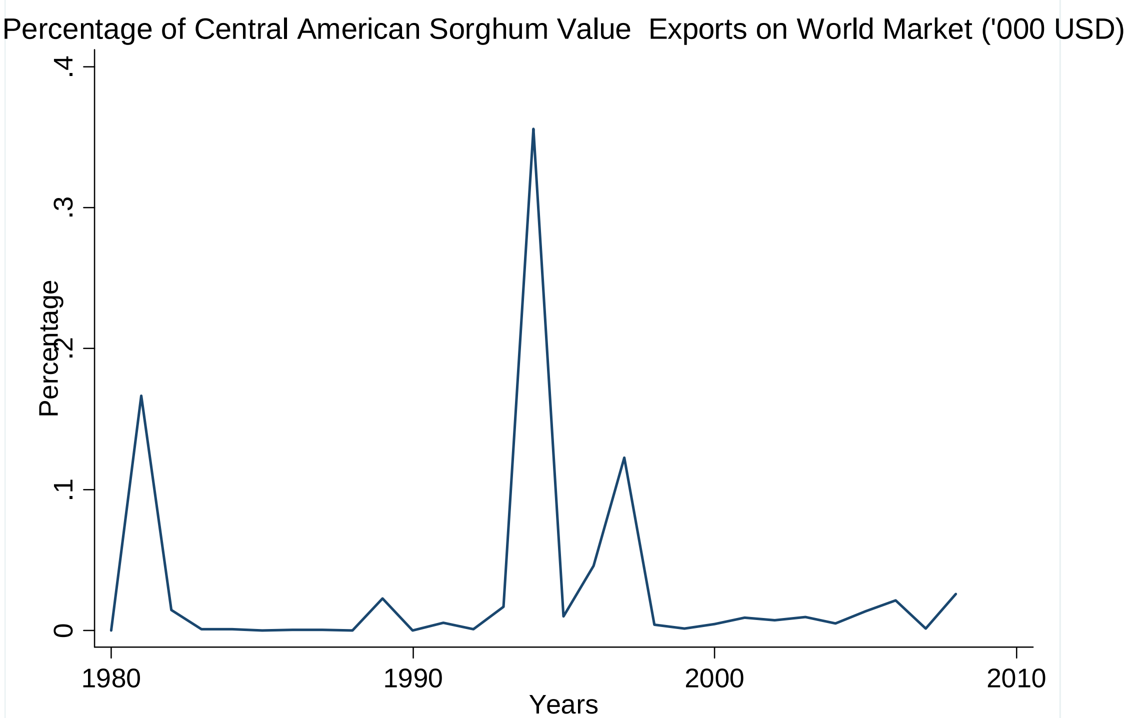

Percentage of South African Sorghum Quantity Imports on World Market (tonnes)
Percentage
0
1
2
3
4
1980
1990
2000
2010
Years


Percentage of South African Sorghum Value Imports on World Market ('000 USD)
Percentage
0
2
4
6
8
1980
1990
2000
2010
Years

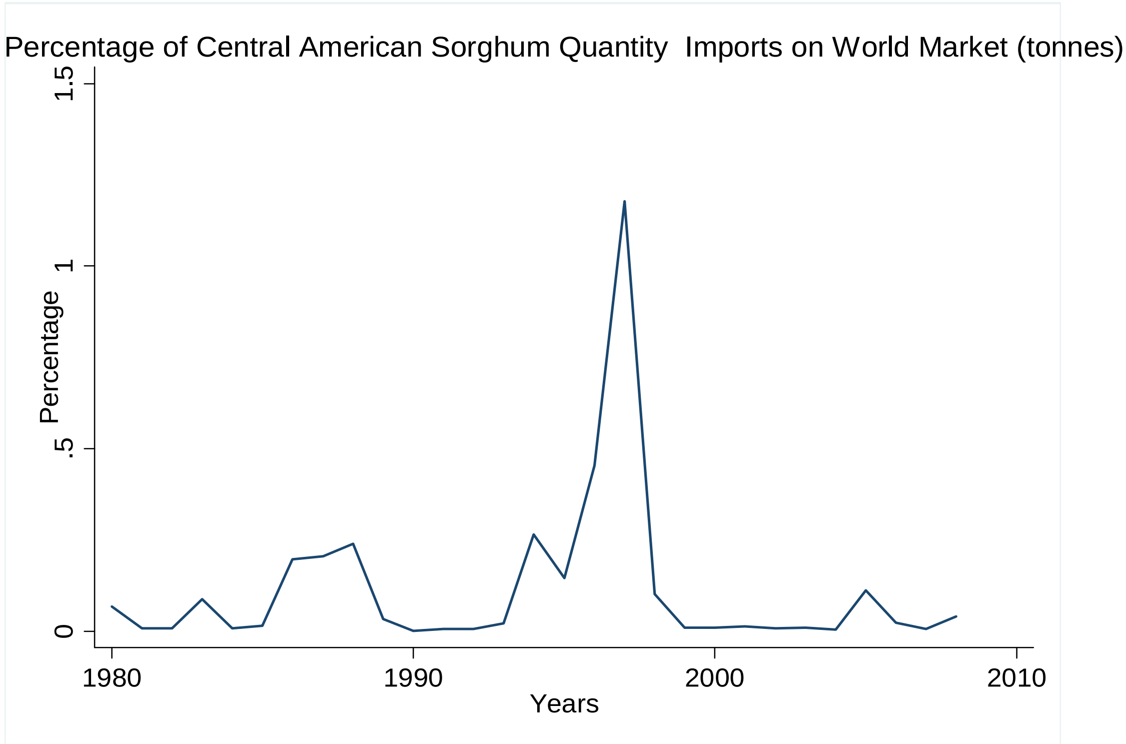
Central America

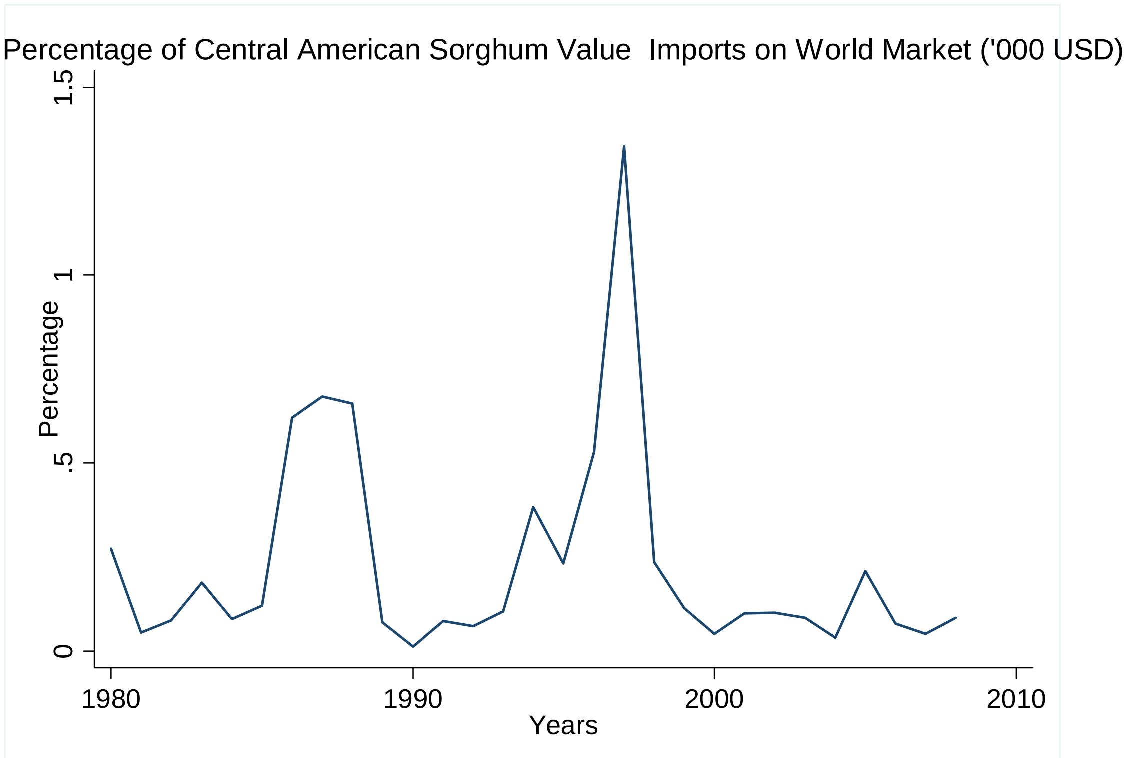
Exports





Imports

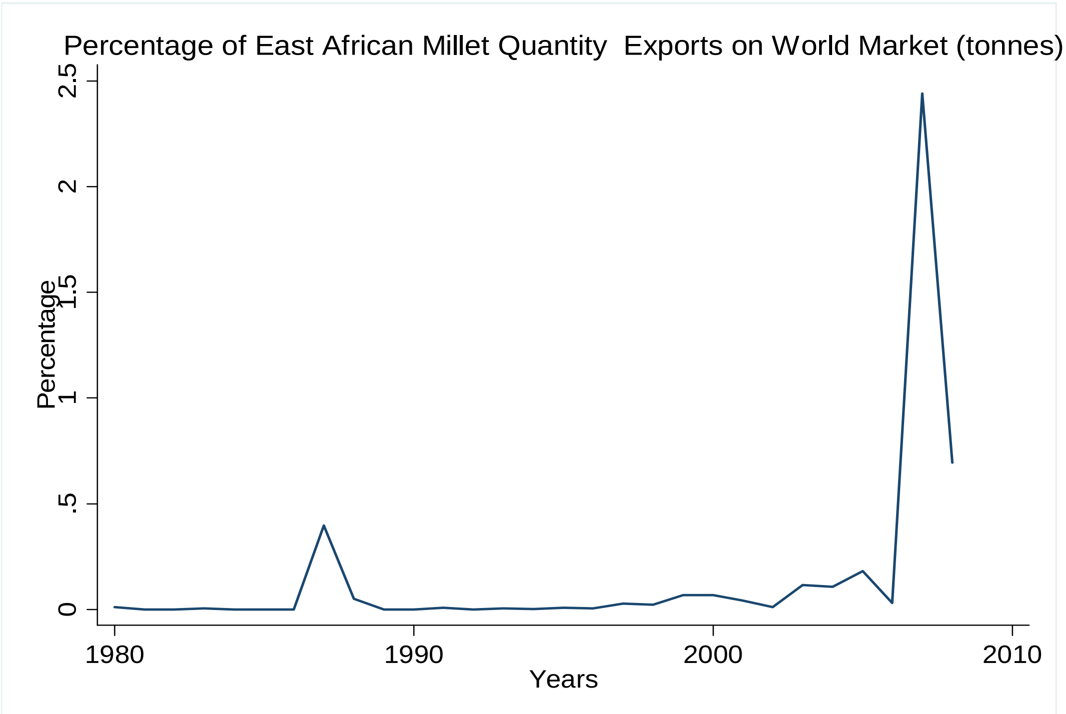

Percentage of Central American Sorghum Quantity Imports on World Market (tonnes)
Percentage
0
.5
1
1.5
1980
1990
2000
2010
Years


Percentage of Central American Sorghum Value Imports on World Market ('000 USD)
Percentage
0
.5
1
1.5
1980
1990
2000
2010
Years

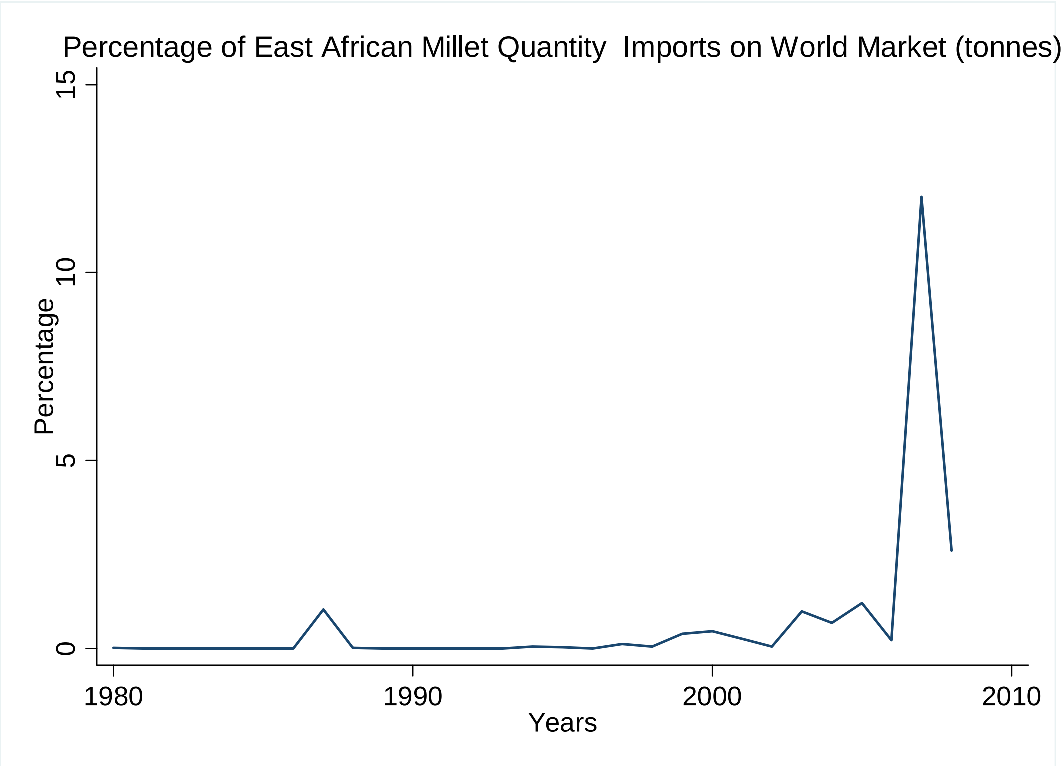
Millet Traded from the different regions covered by INSORMIL

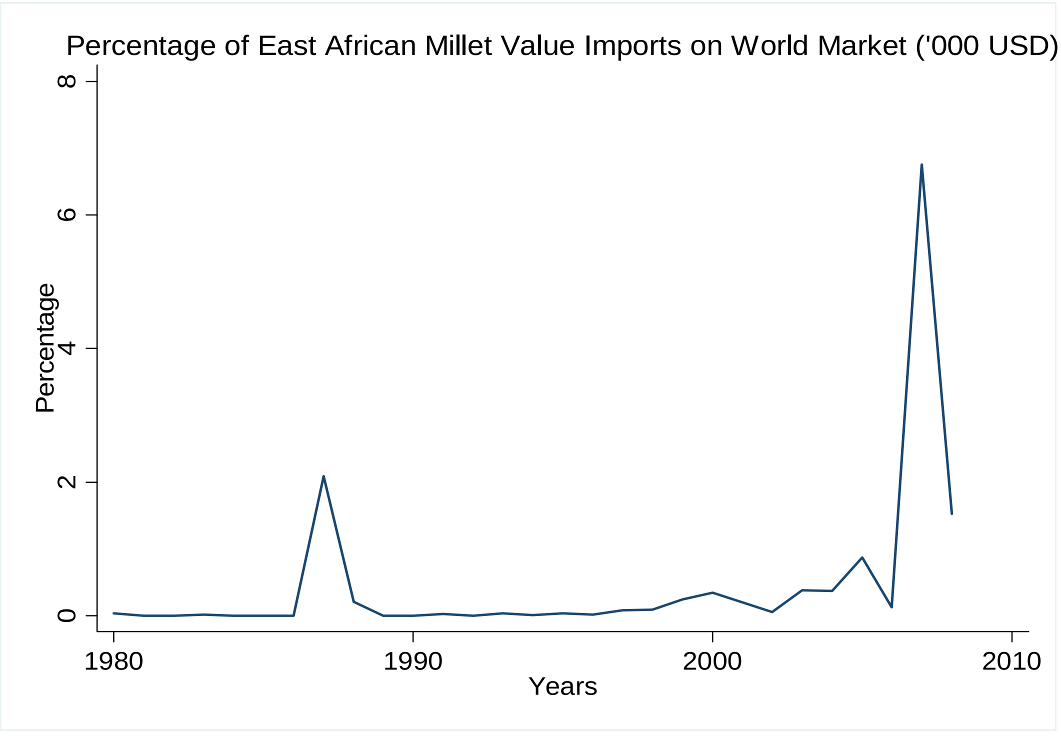
East Africa

Exports



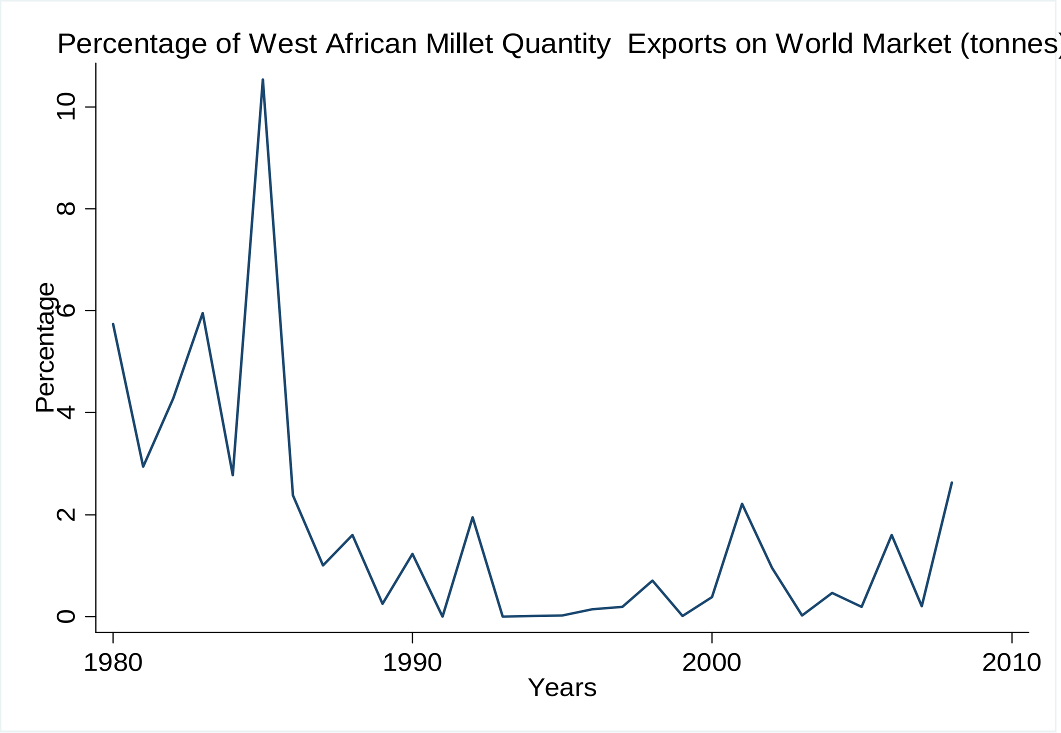
Imports


Percentage of East African Millet Quantity Imports on World Market (tonnes)
Percentage
0
5
10
15
1980
1990
2000
2010
Years

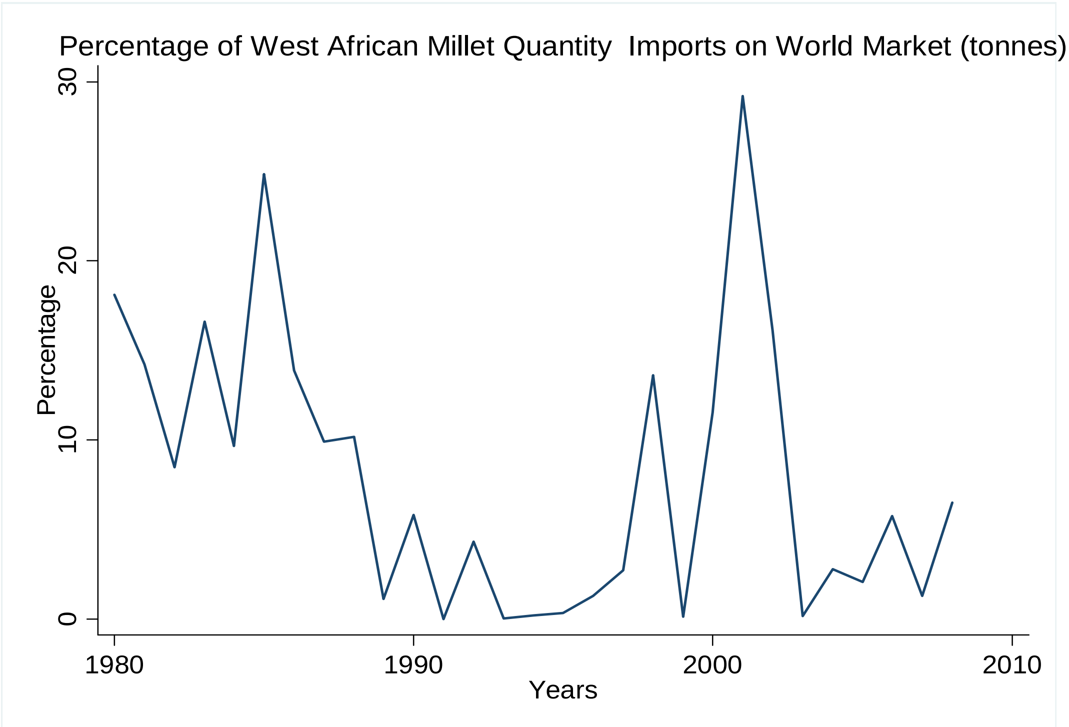

Percentage of East African Millet Value Imports on World Market ('000 USD)
Percentage
0
2
4
6
8
1980
1990
2000
2010
Years

West Africa

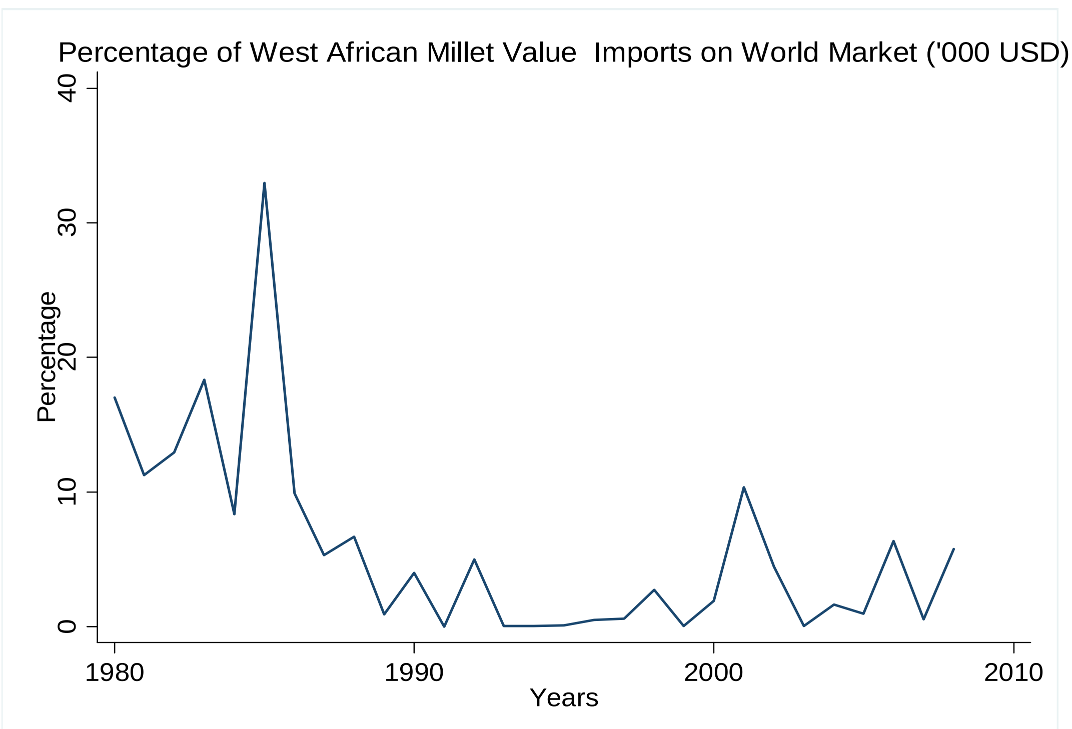
Exports



Imports



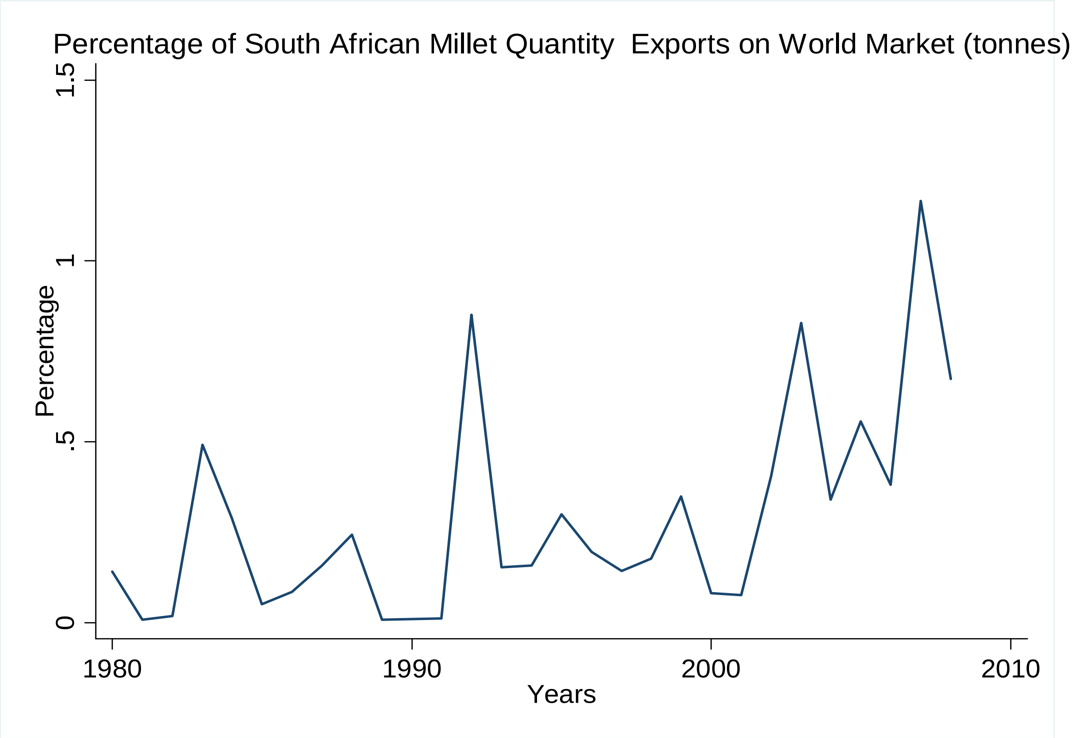
Percentage of West African Millet Quantity Imports on World Market (tonnes)
Percentage
0
10
20
30
1980
1990
2000
2010
Years

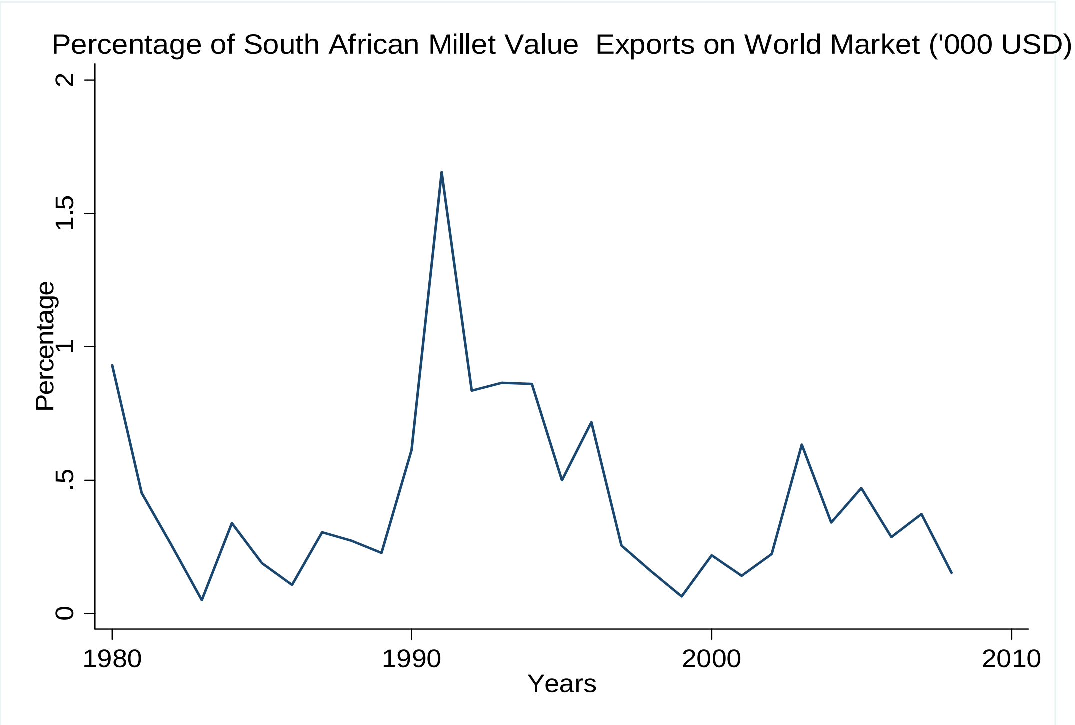


Percentage of West African Millet Value Imports on World Market ('000 USD)
Percentage
0
10
20
30
40
1980
1990
2000
2010
Years

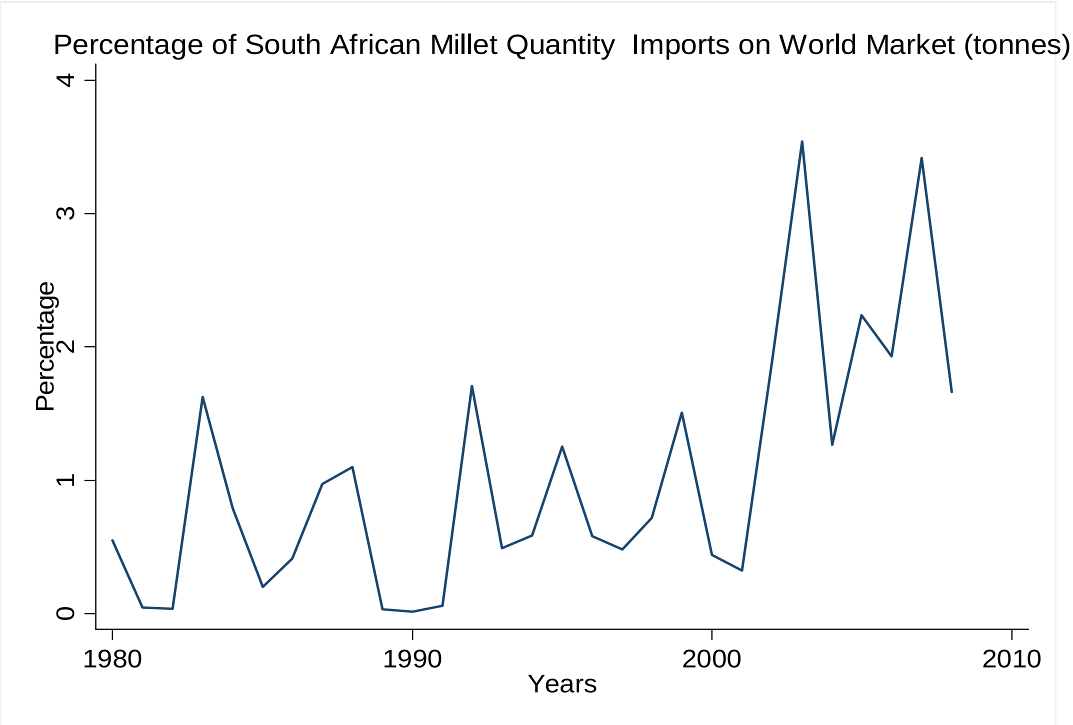
Southern Africa

Exports





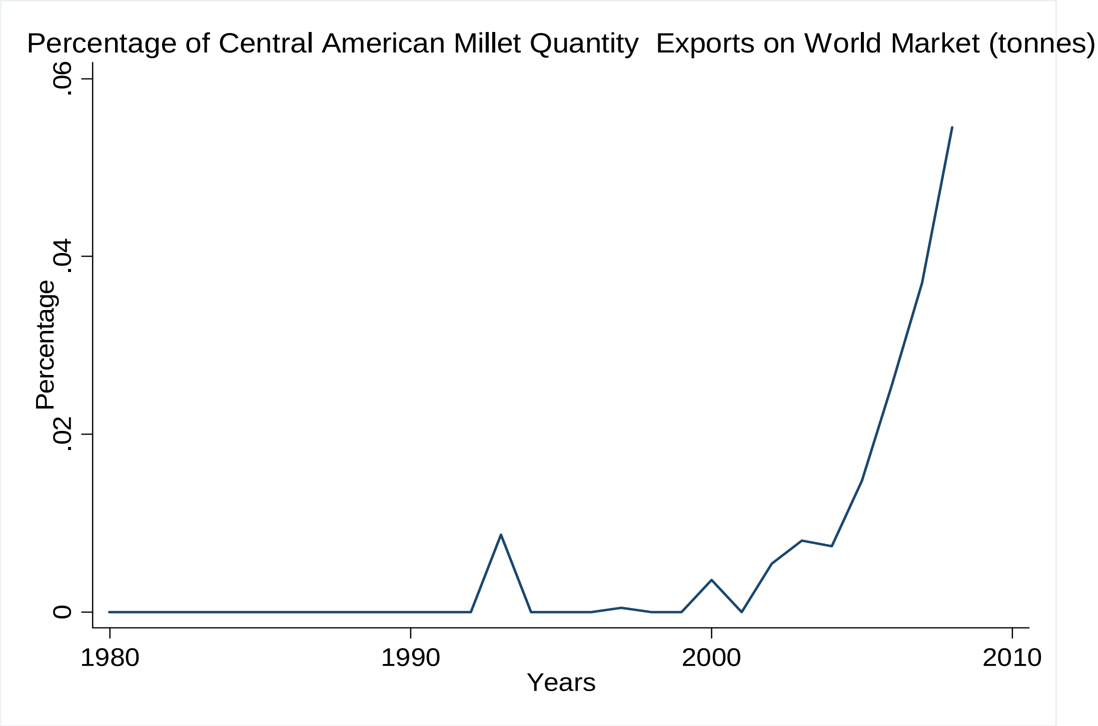
Imports

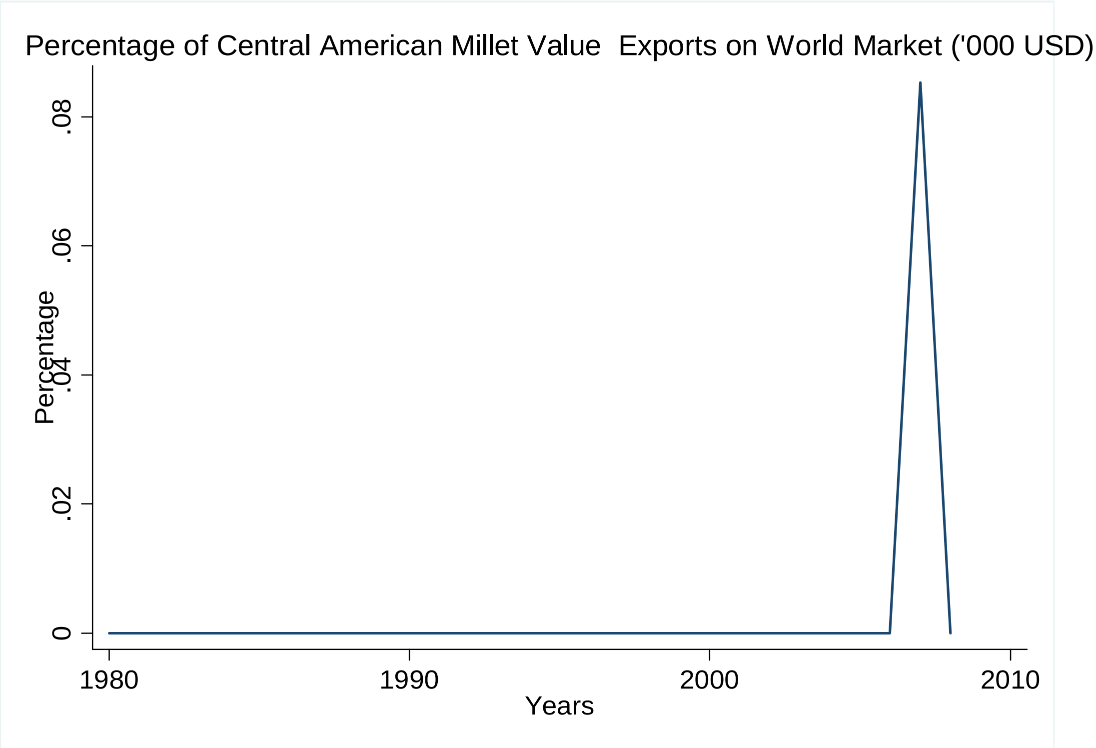

Percentage of South African Millet Quantity Imports on World Market (tonnes)
Percentage
0
1
2
3
4
1980
1990
2000
2010
Years


Percentage of South African Millet Value Imports on World Market ('000 USD)
Percentage
0
1
2
3
1980
1990
2000
2010
Years

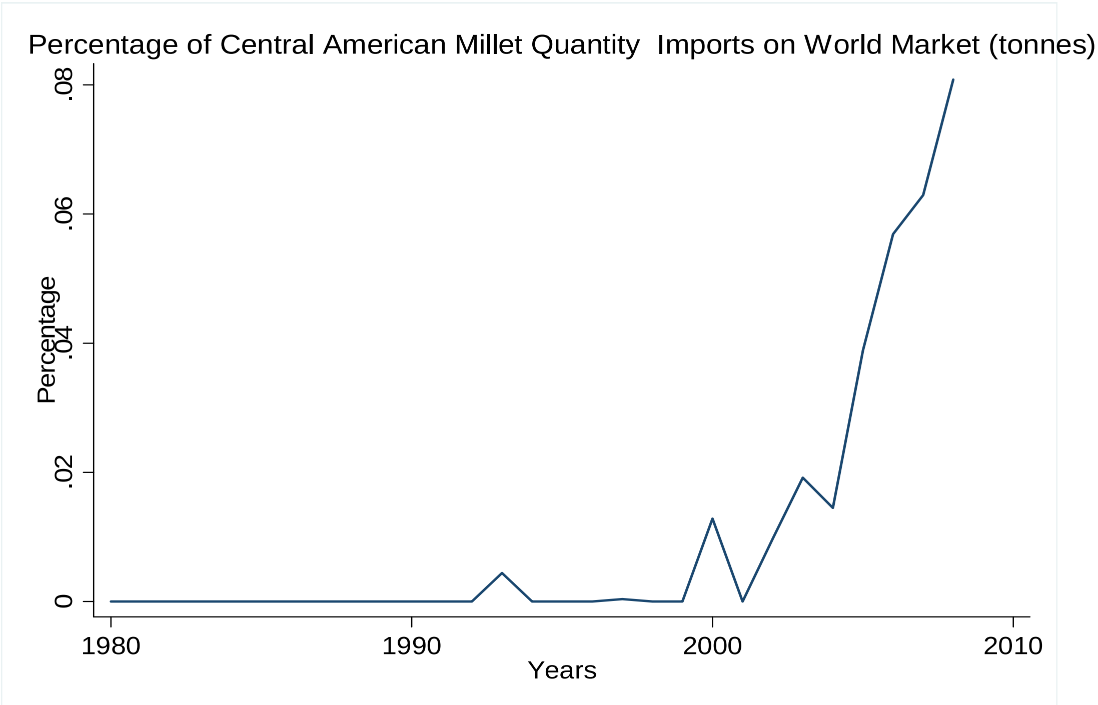
Central America

Exports

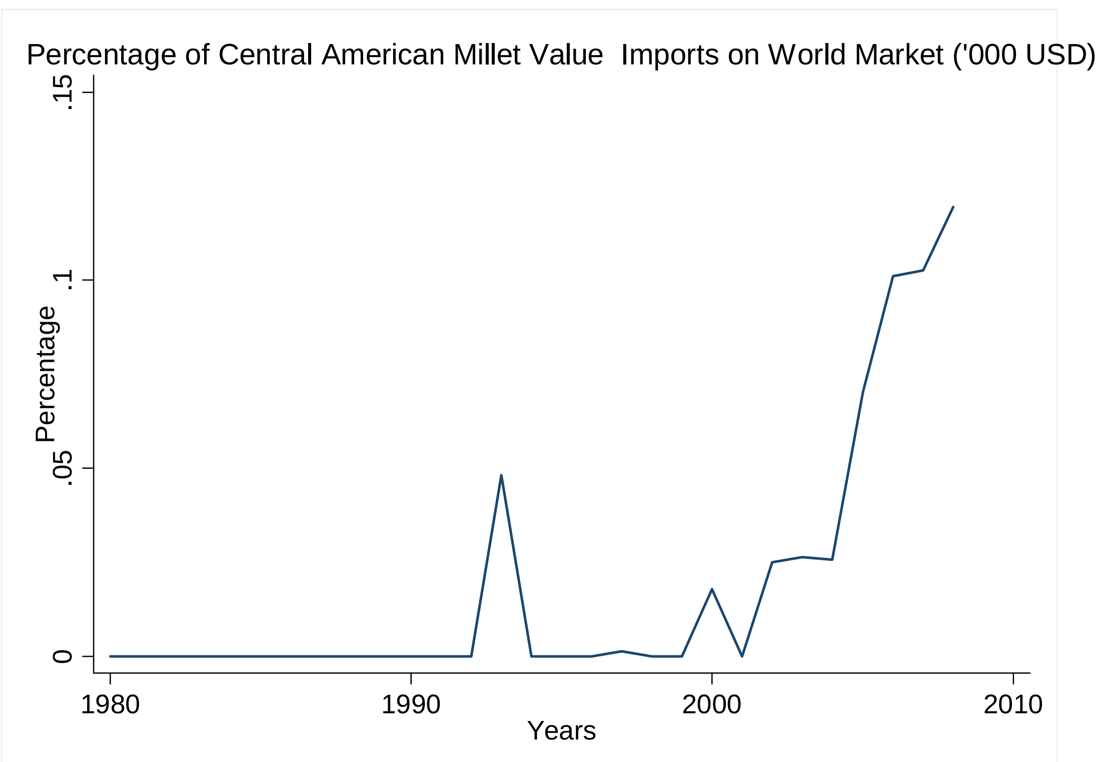




Imports



Percentage of Central American Millet Quantity Imports on World Market (tonnes)
Percentage
0
.02
.04
.06
.08
1980
1990
2000
2010
Years



Percentage of Central American Millet Value Imports on World Market ('000 USD)
Percentage
0
.05
.1
.15
1980
1990
2000
2010
Years

Appendix 3. List of the officially released varieties (cultivars and hybrids) through INTSORMIL/US/host country collaborations.

A detailed list of the officially released varieties (cultivars and hybrids) through INTSORMIL/US/host country collaborations is contained in the following table.

S.No.	Country	Variety	Year of Release	Remark
1	Sudan	Hageen Dura-1	January, 1983	• Through ICRISAT/INTSORMIL/ARC collaboration. • The female line Tx623 (from INTSORMIL / Texas) was used due to its wide adaptation, high yield potential and drought resistance.
	Sudan	SRN-39	1991	• line (P-9679083) -*Striga* tolerant/resistant line • released for production in Sudan
	Sudan	Ingaz (=M90393 = Salvation Government)	1993	• high yielding local **varieties** • ingaz is grown under irrigation •
	Sudan	Feterita Wad Ahmad (=Cr35:18).		• high yielding local **varieties** • Feterita Wad Ahmed for both rained and irrigated conditions
2	Ethiopia	Gubiye (P9401) ,	1999/2000	• *Striga* resistant varieties
	Ethiopia	Abshir (P9403)	1999/2000	• *Striga* resistant varieties
	Ethiopia	Brhan(PSL5061)	2002	• *Striga* resistant varieties
3	Kenya	P-898012		• Drought tolerant line • May have come from ARC/ICRISAT program in Sudan (INTSORMIL annual report, 1989).

4	Tanzania	Hakika (P9405)	2002	• *Striga* resistant varieties
	Tanzania	Wahi (P9406)	2002	• *Striga* resistant varieties
5	Niger	NAD-1	1992	• Drought tolerant sorghum hybrid NAD-I = Tx623 x MR732 • **hybrid**
	Niger	Sepon 82 (=M90382) (=M90382)		• high-yield varieties (in collaboration with ICRISAT)
	Niger	Midge resistant varieties		• Midge resistant varieties
	Niger	SRN39 (=ICSVI007 BF)		• *Striga* resistant **varieties** • in collaboration with ICRISAT
	Niger	IS9830		•
	Niger	MM		• high-yield cultivars
	Niger	IRAT 204		• high-yield cultivars
	Niger	90SN7		• high-yield cultivars
	Niger	TX623A		• hybrid parental lines
	Niger	223A		• hybrid parental lines
	Niger	F1-223		• hybrids
	Niger	SSD35		•
6	Mali	Malisor lines[8] (84-1 to 84-7)	1987	• excellent head bug resistance • Seven improved sorghum lines from the

[8] The Malisors are being used by some farmers under different names (INTSORMIL annual report, 1989).

				Malian program have been released. • These Malisor lines (84-1 to **84-7)** have different maturities and characteristics for the various regions of Mali.
	Mali	Malisor 92-1		•
	Mali	Malisor 92-2		•
	Mali	N'Tenimissa	2000	• tan-plant Guinea type breeding **cultivar**
	Mali	Wassa (97-SB-F5DT-63)	2002	• (N'Tenimissa*Tiemarfing) • tan-plant guinea lines **cultivar** • new N'Tenimissa breeding derivative • Tiemarfing is a Malian local landrace guinea type sorghum.
	Mali	Kénikédiè (97-SB-F5DT-64)	2004	• (N'Tenimissa*Tiemarfing) • true guinea types, but with tan plant
	Mali	Darrellken (99-BE-F5P-128-1)	2004	• (N'Tenimissa*?) • true guinea types, but with tan plant
	Mali	Niéta(97-SB-F5DT-74-2)	2004	• (N'Tenimissa*Tiemarfing) • true guinea types, but with tan plant
	Mali	Zarra-blè(96-CZ-F4P-98)	2004	• (N'Tenimissa*Tiemarfing) • true guinea types, but with tan plant
	Mali	Zarra-djé(96-CZ-F4P-99)	2004	• (N'Tenimissa*Tiemarfing) • true guinea types, but with tan plant
	Mali	Niétichama (97-SB-F5DT-150)	2004	• (92-SB-F4-14*92-SB-F4-97) • intermediate caudatum-guinea type.
	Mali	98-SB-F2-78		•
	Mali	98-BE-F5P-84		• Guinea types for the Sahel zone

	Mali	Grinkan , Tiandougou		• for the Sudan zone.
7	Nigeria	LCICMH-I,	September 1, 2005	• **pearl millet hybrid** • yield potential of 4 t grain/ha, i.e. 33% more grain than farmers' local varieties, and early maturing characteristic.
8	Zambia	WP-13		•
	Zambia	Kuyuma,	1989	• varieties •
	Zambia	Sima	1989	• varieties •
	Zambia	ZSV-15	1998	•
	Zambia	MMSH -375	1992	• hybrids
	Zambia	MMSH -413	1992	• hybrids
	Zambia	MMSH -1257	1998	• hybrids
	Zambia	MMSH-625 and	2007	• higher yield • hybrids
	Zambia	MMSH-1365	2007	• higher yield • hybrids
9	Mexico	BJ-83	1983	• hybrids
	Mexico	BJ-85	1983	• hybrids
10	Honduras	Enhanced maicillos		• drought, insect and disease resistance-superior yields of quality sorghum
	Honduras	Tortillero (CS3541 Sel.)	1982	• white seeded, food type sorghums that produce good quality tortillas • photoperiod insensitive improved sorghums • **varieties**
	Honduras	Catracho (ATx623 x Tortillero)	1984	• ATx623*Tortillcro • white seeded, food type sorghums that

				produce good quality tortillas • hybrid • photoperiod insensitive improved sorghums
	Honduras	Ganadero	1994	• ATx623*Tx2784 • hybrid • The downy mildew resistant male parent, Tx2784, was developed jointly in projects TAM-124 and TAM-I22.
	Honduras	Sureno [(SC423 x CS3541) E35-1	1985	• Superior grain quality, high yield potential, disease resistance, and dual purpose use for both forage and grain. • **Varieties** • an open pollinated variety • white seeded, food type sorghums that produce good quality tortillas • photoperiod insensitive improved sorghums
11	Guatemala	ICTAM777		same as ATX623 X Tortillero
	Guatemala	Gigante Mejorado		• new improved varieties, have shown outstanding performance across five testing locations in Honduras
	Guatemala	Porvenir Mejorado.		• improved varieties, have shown outstanding performance across five testing locations in Honduras
	Guatemala	CENTA SS-44 (ICSA275xTX2784)	2001-1007	• Forage hybrid for green chop use in intensive dairy production • in El Salvadoris being adopted as a dual-use grain/forage variety.
	Guatemala	INTA	2001-1007	• Forage hybrid for green chop use in intensive dairy production

		Forajero		• in El Salvadoris being adopted as a dual-use grain/forage variety.
12	El Salvador	CENTA SV-3	2004	• the Honduran variety Sureño
	El Salvador	variety RCV		• silage to maintain milk production during the dry summer season
	El Salvador	INTA Forajero	2001-1007	• This forage sorghum hybrid has high palatability, digestibility and nutritional quality, has been shown to increase milk production 25% over previously used forage sorghum varieties • widely adopted by dairies in El Salvador
	El Salvador	INTA Forajero	2001-1007	• This forage sorghum hybrid has high palatability, digestibility and nutritional quality, has been shown to increase milk production 25% over previously used forage sorghum varieties • widely adopted by dairies in El Salvador
13	Nicaragua	INTA RCV	April 29,2008	•
13	Nicaragua	INTA SR-16	April 29,2008	•
13	Nicaragua	INTA Forrajero	April 29,2008	•
	Nicaragua	INTA Trinidad		• white-grained, early maturity varieties adapted to low rainfall areas with less than 800 mm per year
	Nicaragua	INTA Ligero		• white-grained, early maturity varieties adapted to low rainfall areas with less than 800 mm per year
	Nicaragua	INTA CNIA		• White-grained variety for higher rainfall areas with over 800 mm per year.
	Nicaragua	ZAM-ROJO	2000	• hybrid
	Nicaragua	Oro Blanco		•
	Nicaragua	Diamante		•
	Nicaragua	INTA Segovia	January 14, 2011	• INTA Segovia, under drought conditions, produces higher yields than currently grown sorghum varieties.

				• INTA Segovia is a sorgo millón (improved) Maicillo Criollo (native sorghum)
14	Columbia	Sorgo Real 40(156-P5 Serere-1)	January, 1991	• Al-tolerant varieties • These cultivars produce profitably in soils with **60% Al** saturation, immediately making more than 200,000 hectares of marginal farm land available for sorghum production in Colombia alone. • **varieties**
	Columbia	Sorgo Real 60 (MN 4508)	January, 1991	• Al-tolerant varieties • These cultivars produce profitably in soils with **60% Al** saturation, immediately making more than 200,000 hectares of marginal farm land available for sorghum production in Colombia alone. • **varieties**
	Columbia	Icaravan 1 (IS 307 **1)**	1993	• Al-tolerant varieties • acid soil tolerant • These cultivars produce profitably in soils with **60% Al** saturation, immediately making more than 200,000 hectares of marginal farm land available for sorghum production in Colombia alone. •
	Columbia	Icaravan 2 (IS 8577).	1993	• Al-tolerant varieties • acid soil tolerant • These cultivars produce profitably in soils with **60% Al** saturation, immediately making more than 200,000 hectares of marginal farm land available for sorghum production in Colombia alone. •
15	Puerto Rico	GTPP7R (H) C5	1989	• high levels of resistance to anthracnose, rust, and other foliar diseases in a diverse genetic background • Excellent disease resistance as well as white grain tan plant color • possessing grain with desirable food properties
16	China	line Tx622		• The line Tx622 (a sister line to AT623 in Hageen Dura) has been introduced to

				China, and is used in hybrids planted on tens of thousands of hectares
	West Africa region	PU-KS10 and PU-KS11	2009	• Acetolactate Synthase (ASL) herbicide resistant derivatives of N223 • released to the U.S. seed industry • joint releases by KSU and Purdue
	Ghana, Chad, Senegal, Mali, Niger, Sudan, Somalia, Rwanda, Mozambique, Eritrea, and Ethiopia.	*Striga* resistant varieties	December 1994	• *Striga* resistant varieties (SRN-39)
	Latin American institutions	Sureno	1985	• Al-tolerant (Aluminum Tolerant) • a grain mould-resistant line • (SC423*CS3541)E35-1. • photoperiod insensitive improved sorghums