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Improving the efficiencies of national crop breeding programs through region-based approaches: the case of sorghum and pearl millet in southern Africa

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Abstract

Resources available for agricultural research have fallen sharply in many national agricultural research systems (NARS) and international agricultural research centers. Therefore, it is becoming increasingly important that decision makers focus on improving the efficiency of national and international agricultural research. Breeding and variety release systems have remained largely focused on national challenges while seed markets are becoming globalized. This paper reports on studies and analyses of sorghum and pearl millet breeding and variety release systems conducted in Southern Africa Development Community countries. A synthesis is presented to provide a scientific and economic justification for improving the efficiency of the systems in SADC. It further proposes a regionalized breeding strategy that improves the efficiency in utilizing resources for crop breeding. Geographic information system analysis was used to delineate the region into four recommendation domains or agro-ecological zones (AEZs) based on length of growing period of the crop that cut across country borders. The AEZ together with multiple variety releases exemplify potential adaptability of the varieties across country borders. Sequential retrospective pattern analyses using grain yield data from multiple environment trials conducted over 12 years, stratified the 39 SADC test sites into 6 groups according to their similarity in line-yield. This provided an objective basis for selecting a few potentially useful and representative benchmark test sites for efficient regionalized variety testing in the future without loss of scientific information. NARS and International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) breeders have proposed a "Lead NARS" approach of regionalized breeding as a strategy for increasing the efficiency, cost effectiveness and sharing of regional responsibilities. Mechanisms for regionalized release procedures to facilitate farmer access to new improved varieties will alleviate problems of access to seed by farmers as well as the challenges facing small seed markets.

Key words: agro-ecological zones, plant breeding, sorghum, pearl millet, varieties.

Introduction

Many African countries have lost ground with regard to financing their agricultural research and development (RD) activities. Consequently, the importance of donor support has increased markedly. The financial support for RD from donors increased from 34% in 1986 to 43% in 1991 [9]. However, such assistance is available for a limited duration. For instance, the Southern Africa Development Community (SADC) Sorghum and Millet Improvement Program (SMIP) was initiated in 1983 and ended in 2003. The program expended US$41.0 million during the 20 year implementation period largely on national agricultural research system (NARS) capacity building, salaries of internationally recruited scientists, development of infrastructure and operational costs for research work. The International Crops Research Institute for Semi-Arid Tropics (ICRISAT) was the implementing agency taking responsibility for strengthening the SMIP in each of the then eight-targeted SADC countries [4]. ICRISAT developed and provided germplasm to NARS scientists who subsequently established multi-location variety testing systems for both their own and the ICRISAT germplasm. By 2003, the national programs had released 49 improved sorghum and pearl millet varieties but almost 50% of the NARS scientists trained under the SMIP had left the national programs for more lucrative jobs elsewhere. In addition, NARS were faced with declining funding for RD thus weakening the sorghum and millet breeding programs. Therefore, it was imperative to improve the efficiency in utilizing the limited resources at their disposal.

In this paper we present and summarize a key strategy for improving the efficiency and impact of agricultural research investment by targeting technology development at the regional rather than national level. We present a comprehensive strategy on how new improved crop varieties can be developed and linked to regional variety registration that supports technology dissemination on a relatively large scale targeting many farmers across the SADC region. Based on the analyses of case studies drawn from the region, the paper presents justifications for adopting a regionalized breeding approach and proposes a *modus operandi* for such an approach as a new institutional arrangement to enhance efficiency in agricultural research. The implications of the regionalized crop breeding and variety registration approach on access to seed and seed trade in the region are discussed.

Materials and Methods

For justifying a regionalized breeding approach, we used information obtained from

i). environmental characterization and delineation of recommendation domains, to elucidate that agro-ecological zones (AEZs) for optimum crop production overlap national borders

ii). analyses of historical multi-environment trials (METs) data to improve biophysical characterization and stratification of test sites and

iii). multiple variety releases across countries in the SADC region.

Agro-ecological zonation using geographical information system (GIS): Sorghum and millet researchers in the region, based on their experiences delineated areas where, historically, the two crops predominantly were grown. In addition, geo-referenced climatic data derived from a dataset consisting of interpolated monthly values of precipitation, potential evapo-transpiration, ratio of precipitation to potential evapo-transpiration (P/PE), minimum temperature and maximum temperature for the whole SADC region was used[1]. Using this database and climatic data, AEZ were mapped out out. A total of 39 geo-referenced SADC test sites were overlaid on the zonations in order to determine the sites that are in the same agro-ecological zone as well as the major biophysical characteristics of these sites for sorghum and millets (Table 1).

Analyses of historical MET data to improve biophysical characterization and stratification of test sites: In a large region, such as the SADC, knowledge of crop production zones within the region are useful in selecting test sites as well as the varieties that attain optimum productivity in the respective environments. The number and location of test sites are critical factors that influence the efficiency of crop breeding. The test sites must be representative of the conditions of the target production areas. It is necessary to have sufficient sites to cover the main target environments but a large number of sites increases research costs. SMIP addressed this problem by re-analyzing long-term yield data from trials conducted at numerous sites by various NARS, in order to group these testing sites according to similarity of cultivar response to varying production conditions. Sequential retrospective (SeqRet) pattern analysis was used for stratification of the testing sites according to their similarity of genotype-yield differentiation patterns [2, 6]. The stratification methodology was described recently [3, 7]. The stratification was done using data from 90 and 147 METs (conducted in the region) for pearl millet and sorghum respectively. The pearl millet METs were conducted across 25 sites over nine years (1989/90 to 98/99) while those for sorghum were conducted across 34 sites over seven years (87/88 to 92/93 and 99/2000).

The southern Africa region was grouped according to the length of growing period (LGP), i.e. the period when water and temperature regimes permit crop growth (Fig 1). It is also a continuous period with rainfall more than half of the potential evapo-transpiration, excluding periods when temperatures are below levels required for crop growth.

Multiple variety releases and economic analyses to justify regionalized variety registration: By 2003, NARS in southern Africa in collaboration with ICRISAT released a total of 49 improved sorghum and pearl millet varieties. Most of these releases were done independently through national release systems of individual countries. However it was also realized that there were multiple variety releases in which individual genotypes were released in more than one country but at different times. A survey was conducted across eight SADC countries to determine the multiple variety releases and the period of release. An analysis on the cumulative production gain derived from national versus regional release was done on a representative sorghum variety Macia (initially released in Mozambique in 1989 and subsequently in Tanzania in 1999), to provide an economic justification for the harmonization of seed laws and regulations (in SADC) especially with respect to regional variety registration (Table 2). Data were subjected to GIS mapping procedures in order to determine other areas (outside the country of commercial release) in the SADC region where such varieties could be adapted [8].

Results

Agro-ecological zonation using geographical information system (GIS): The results indicated that the average LGP for the bulk of pearl millet growing areas was 4 ± 1 months (Fig. 1). The LGP for at least 75% of the sites ranged from 3 to 6 months. Egually important, environments and constraints cut across country borders suggesting firstly that outputs of a breeding program in one country can be adapted and used in similar environments in other countries. Secondly, under diminishing resources, regionalized breeding approaches could potentially improve efficiency in cultivar development and exploit the spillover of adaptation for cultivar dissemination.

Multiple variety releases and economic analyses to justify regionalized variety registration: Results of the analyses of released varieties indicated presence of multiple sorghum and pearl millet variety releases across the SADC region. The varying national variety testing, registration and release schemes for each country resulted in a lapse of many years between the first and last release for Macia. An economic analysis (Fig. 2) on the individual national releases for Macia across the five countries compared with a hypothetical regional registration approach demonstrated a cumulative loss of approximately US$43m as a result of fragmented national release schemes. This suggested that in order for other countries to benefit from these releases, they need to utilize major test sites and areas of adoption for each of these multiple released varieties.

There was a similar pattern in terms of the adaptability areas for sorghum variety Macia (Fig. 3) and pearl millet variety PMV2 (Fig. 4). However, the adaptability area for the sorghum was wider than that of the pearl millet variety.

Discussion

The results from agro-ecological zonations, stratification of sorghum and pearl millet test sites and multiple variety releases were shared broadly with both public as well as private partners in southern Africa. ICRISAT / SMIP in the SADC region demonstrated the practicality of regionalized breeding. The results demonstrated scientific and economic justifications for shifting the focus of crop breeding from independent national investments toward a coordinated regionalized investment. Consequently sorghum and pearl millet breeders in southern Africa agreed on a

Table 1. Biophysical characteristics of SADC sorghum variety test sites.

Site	Longitude	Latitude	LGP	First Month	Altitude (m)	Annual Rainfall (mm)	Min Temp. (^{0}C)	Max Temp. (^{0}C)	Soil Texture	SWHC	PH	DRAINAGE
Luanda (Ang)	13.23	-8.85	2	12	40	374	22	27	Coarse	Medium	6.4	High
Good Hope (Bot)	25.47	-25.47	1	3	1232	500	11	27	Coarse/Medium	Very Low	6.3	Somewhat Excessively Drained
Sebele (Bot)	25.95	-24.58	2	11	976	495	12	28	Medium/Fine	High	6.4	Moderately Well Drained
Pandamatenga (Bot)	25.65	-18.27	4	12	1070	671	14	30	Coarse	Very Low	6.4	Somewhat Excessively Drained
Maseru (Les)	27.55	-29.45	4	12	1501	669	8	23	Medium/Fine	Low	6.2	Well Drained
Ngabu (Mal)	34.93	-16.48	4	11	115	760	19	32	Fine	High	7.3	Imperfectly Drained
Kasintula (Mal)	34.75	-16.12	4	12	122	793	19	32	Fine	Medium	6.6	Poorly Drained
Makoka (Mal)	35.20	-15.20	5	11	650	885	18	28	Medium	Very Low	7.1	Well Drained
Nampula (Moz)	39.28	-15.10	5	10	329	1045	19	31	Medium/Fine	Very Low	6.4	Well Drained
Chokwe (Moz)	32.98	-24.53	4	11	33	646	17	31	Fine	Medium	6.8	Poorly Drained
Chimoio (Moz)	33.48	-19.13	5	11	610	1106	16	26	Medium/Fine	Low	5.1	Well Drained
Umbeluzi (Moz)	32.30	-26.00	5	12	64	667	17	29	Medium	High	6.4	Well Drained
Mashare (Nam)	20.22	-17.88	4	1	1061	568	14	31	Medium	Medium	6.6	Imperfectly Drained
Mahanene (Nam)	15.15	-17.45	3	11	1110	505	13	29	Coarse	High	6.4	Well Drained
Okashana (Nam)	16.50	-18.30	3	1	1097	446	15	31	Coarse	High	8.5	Well Drained
Luve(Swa)	31.22	-26.30	7	10	986	982	12	24	Fine	Low	5.1	Well Drained
Nhlangano (Swa)	31.12	-27.06	7	10	993	855	13	25	Fine	Low	5.1	Well Drained
Malkerns(Swa)	31.15	-26.55	7	12	763	890	13	26	Medium/Fine	High	6.2	Well Drained
Bigbend (Swa)	31.95	-26.82	4	12	102	593	16	29	Fine	Low	5.7	Imperfectly Drained

Site	Longitude	Latitude	LGP	First Month	Altitude (m)	Annual Rainfall (mm)	Min Temp. (^{0}C)	Max Temp. (^{0}C)	Soil Texture	SWHC	PH	DRAINAGE
Ilonga (Tan)	37.03	-6.77	6	11	914	978	16	28	Fine	Low	5.7	Well Drained
Ukiriguru (Tan)	33.00	-2.68	7	11	1239	952	17	28	Coarse/Medium	Medium	5.4	Imperfectly Drained
Hombolo (Tan)	35.92	-6.00	4	12	1019	562	16	30	Coarse/Medium	Medium	5.4	Moderately Drained
Tumbi (Tan)	32.50	-5.10	6	11	1222	935	16	29	Coarse/Medium	Medium	5.1	Moderately Well Drained
Naliendele (Tan)	38.77	-10.38	5	2	383	876	20	31	Coarse/Medium	Low	5.1	Well Drained
Mt Makulu (Zam)	32.55	-9.38	6	1	1463	1053	15	28	Medium/Fine	Low	5.1	Imperfectly Drained
Golden Valley (Zam)	28.07	-14.88	5	11	1189	909	14	27	Medium/Fine	High	6.4	Moderately Well Drained
Lusitu (Zam)	28.83	-16.13	3	11	326	632	19	32	Coarse	High	6.4	Well Drained
Matopos (Zim)	28.50	-20.37	4	11	1416	591	12	25	Fine	High	6.4	Moderately Drained
Makoholi (Zim)	30.78	-19.83	5	12	1111	628	13	26	Medium	Medium	6.4	Moderately Well Drained
Kadoma (Zim)	29.92	-18.33	5	12	1107	735	14	28	Fine	High	6.3	Moderately Well Drained
Lucydale (Zim)	28.52	-20.37	4	11	1416	591	12	25	Fine	High	6.4	Moderately Drained
Chiredzi (Zim)	31.67	-21.05	3	11	388	544	15	30	Coarse/Medium	Medium	6.4	Well Drained
Muzarabani (Zim)	31.00	-16.41	3	12	427	665	17	32	Medium	High	6.4	Moderately Well Drained
Gwebi (Zim)	30.80	-17.66	5	11	1418	831	11	26	Coarse	High	6.1	Imperfectly Drained
Panmure (Zim)	31.60	-17.30	5	11	1037	817	13	27	Medium	Medium	6	Modeately Well Drained

Key: Sites Ang - Angola; Bot - Botswana; Mal - Malawi; Moz - Mozambique; Nam - Namibia; Swa - Swaziland; Tan - Tanzania; Zam - Zambia; Zim - Zimbabwe.

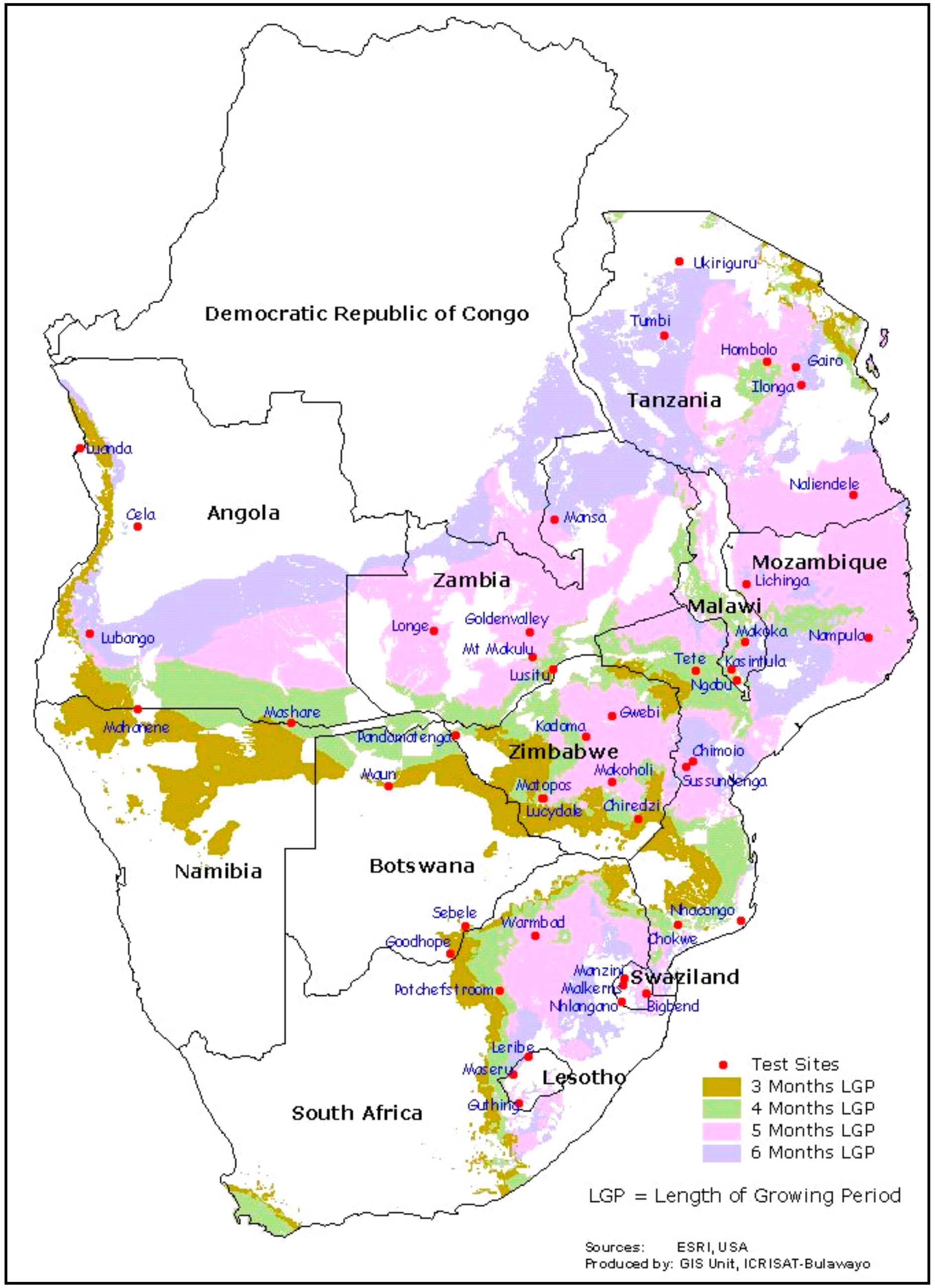

Figure 1. Overlay of test sites and lengths of growing period.

Table 2. SADC multi-country releases of sorghum and pearl millet varieties.

Variety Code	Country of Release	YRCP	Local Name	NYL
SDS 3220	Mozambique	1989	Macia	11
	Botswana	1994	Phofu	
	Zimbabwe	1998	Macia	
	Namibia	1998	Macia	
	Tanzania	1999	Macia	
ICSV 112	Zimbabwe	1987	SV1	6
	Swaziland	1992	MRS12	
	Malawi	1993	Pirira 1	
	Mozambique	1993	Chokwe	
ICMV 88908	Namibia	1990	Okashana 1	9
	Malawi	1996	Nyankombo	
	Botswana	1999	Bontle	
SDMV 93032	Namibia	1998	Okashana 2	2
	Zimbabwe	1996	Okashana 2	
SDMV 89004	Zimbabwe	1992	PMV 2	7
	Botswana	1999	Legakwe	
SDMV 92040	Zimbabwe	1998	PMV 3	0
	Namibia	1998	Kangara	
SDMV 89005	Malawi	1996	Tupatupa	4
	Mozambique	2000	Kuphanjala 1	

YRCP = year of release for commercial production.
NYL = number of years that lapsed from first to last release.

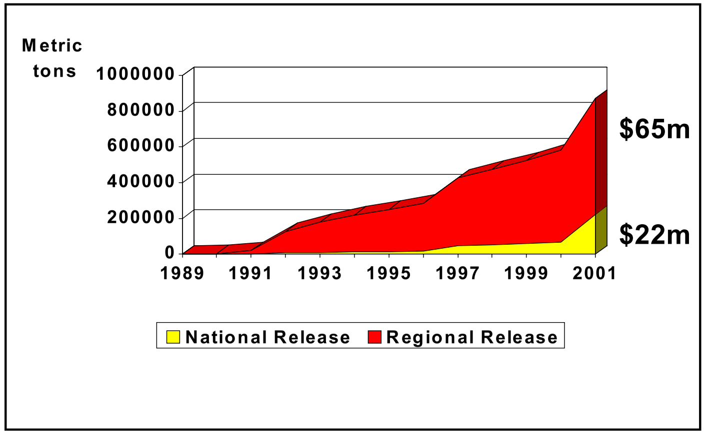

Figure 2. Cumulative production gain derived from national versus regional release of Macia.

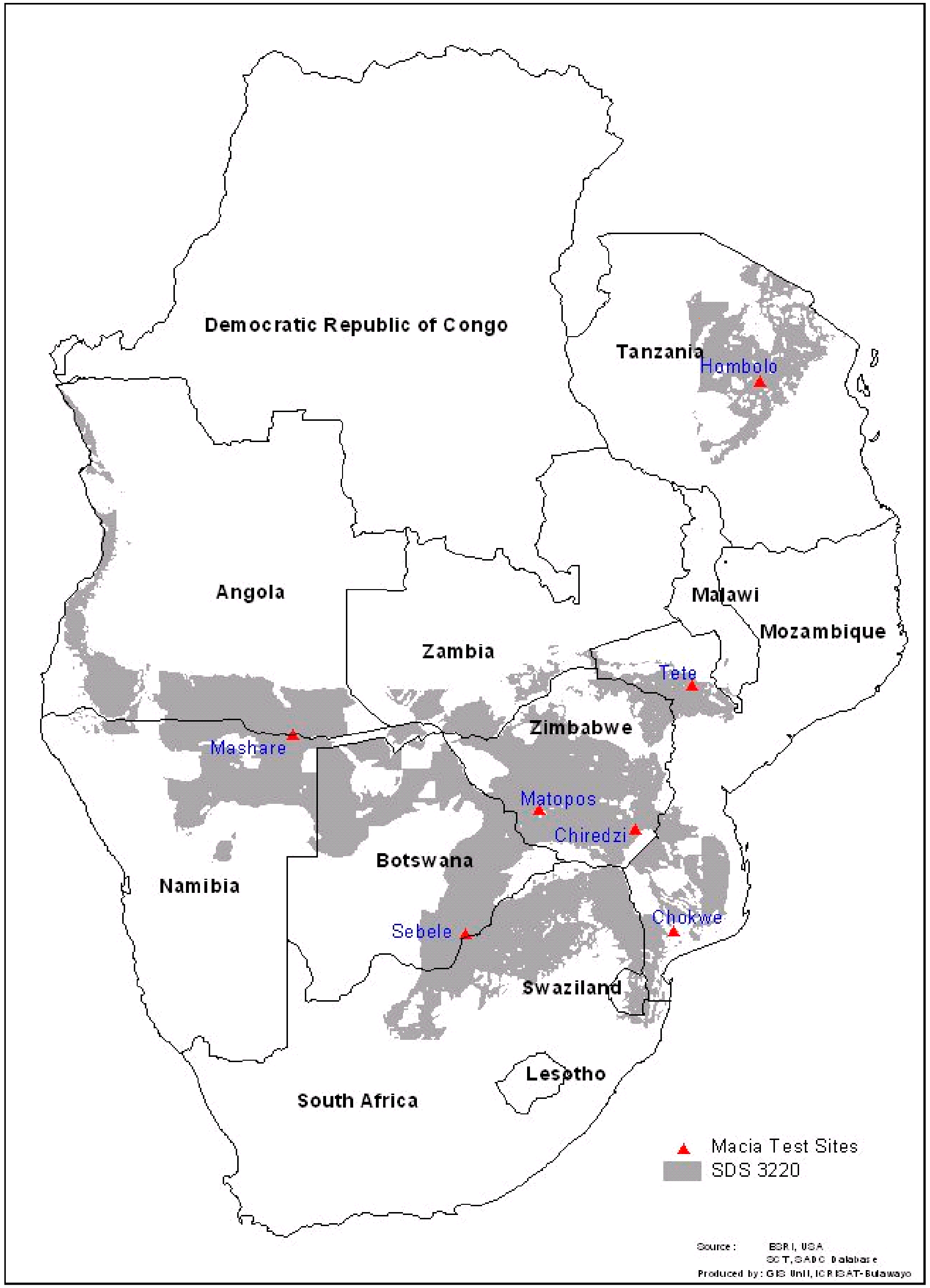

Figure 3. Regional adaptability for Macia.

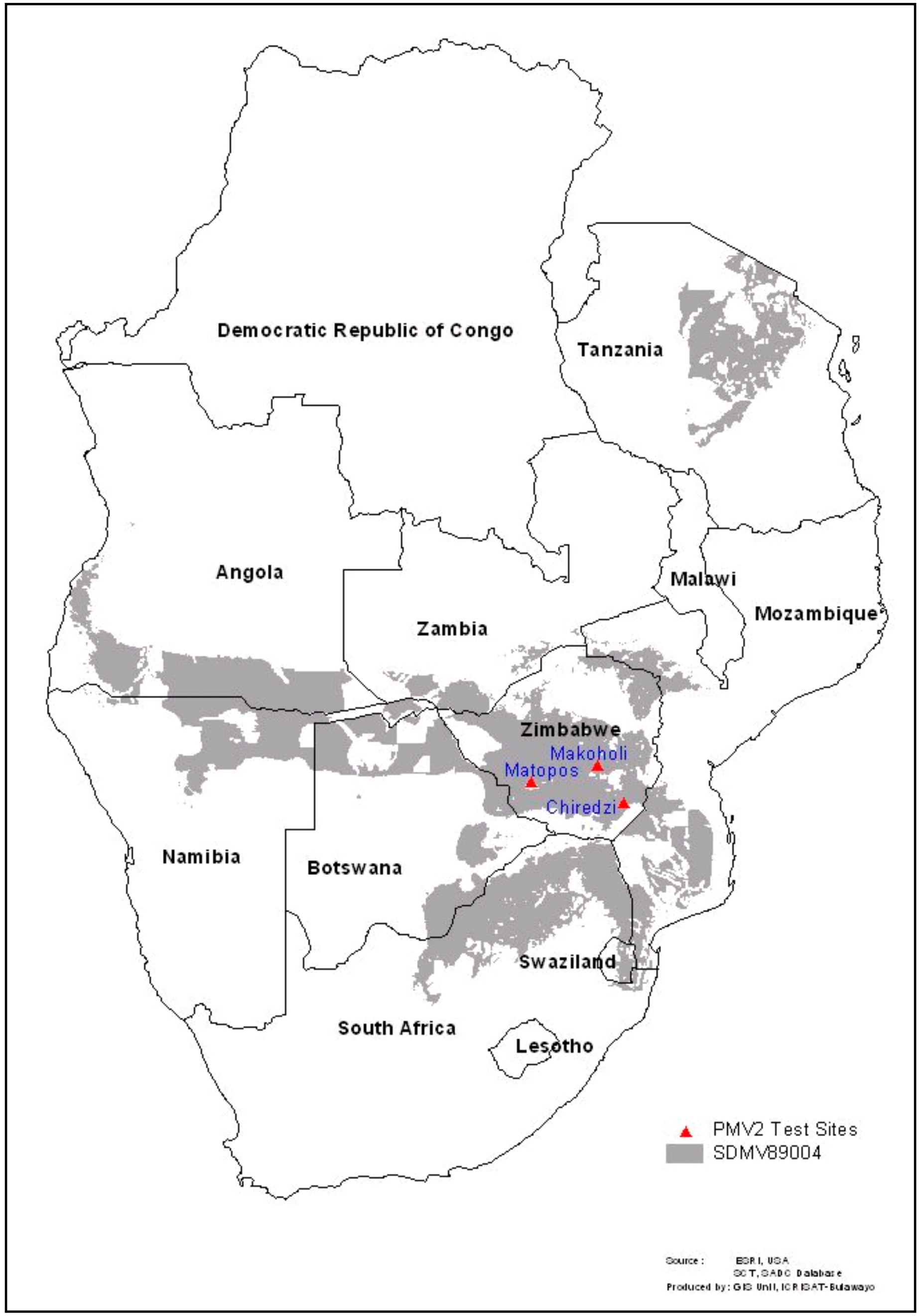

Figure 4. Regional adaptability for PMV2.

formal initiative for regional variety development and referred to it as the "Lead NARS" concept. In this approach, a national program with a comparative advantage is assigned to lead research in a particular research theme on behalf of other NARS with similar problems and AEZs so as to benefit the rest of the national breeding programs through sharing information as well as breeding materials. In this way, the resources for research and development are utilized more economically across the region. For instance, a pilot project focusing on striga is currently being conducted in both Tanzania and Zambia. Tanzania leads the research to incorporate striga resistance into sorghum landraces while Zambia is the lead NARS for improving photoperiod-sensitive sorghum landraces.

There are many implications of these results. Firstly, by inference, countries with larger or more diverse areas of sorghum or pearl millet may be justified in maintaining larger investments in breeding programs for these crops. In contrast, countries with smaller crop areas that are similar to the agro-ecologies of neighbors may be justified in maintaining only small investments aimed at validating the test results obtained from their neighbors. Therefore individual countries could concentrate their resources on crops and agro-ecologies for which they maintain larger or more unique needs.

The results also showed justification for regional, as opposed to national variety release approaches. Regional releases allow the prospect of delivering new varieties more quickly to larger numbers of farmers. Multiple variety testing across national borders can be replaced with a single testing phase aimed at a wider region [8]. Furthermore, these results alluded to the potential of opening regional seed markets. There are no commercial incentives for producing the seed of most open and self-pollinated varieties in SADC. In addition, national seed markets are too small to justify large scale investment in seed production. However, regional seed markets offer the prospects of larger and more stable investment returns. In all probability, a region-based crop breeding approach will allow national breeding programs to share information, responsibilities, expenses, and breeding materials much more efficiently across the region. The regionalization of variety release would strengthen the justification for the investments in these seed markets. A similar approach for breeding programs was proposed [5].

The results from biophysical analyses delineated and mapped AEZs by LGP indicating that multiple environments exist in a given country and that environments cut across national borders. Thus improved outputs of a plant breeding program in one country potentially, can be adapted and adopted in similar environments in other countries. A wider regional program could increase the potential interest of commercial seed companies/entrepreneurs in variety multiplication and distribution. A methodical regionalized breeding can be pursued targeting specific environments at regional level and concomitantly gaining from increased acreage summed across countries. Therefore greater economic benefits from a wide geographic crop area are likely to be derived. Maps of the region showing zones of adaptation of specific (widely adapted) sorghum and pearl millet varieties can strengthen regional seed security and accelerate the spread of improved varieties, reducing the cost of research programs and facilitating the delivery of benefits to farmers. During times requiring seed for relief, the maps generated in this study could be useful in identifying appropriate varieties adapted to afflicted areas or the optimum production areas for such varieties in the region. In future, it may also be possible to set up a regional seed security system in which seed stocks of regionally important varieties could be deposited as regional reserves.

The methodical testing on benchmark sites can support future regional variety registration for an efficient seed system. We are currently pursuing testing in environments grouped based on agro-ecological zonations, known production systems, and site stratification. The SeqRet pattern analysis, exploiting MET data, provided an objective selection method for a few representative test sites. The "Lead NARS" agreed to by ICRISAT in collaboration with NARS breeders and public institutions is model of regionalized breeding that focuses on environmental rather than political boundaries. These initial strategic analyses pursued for sorghum and pearl millet could be extended to other crops such as legumes where the private sector does not have many incentives for marketing the seed.

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