INTERNATIONAL CONFERENCE OF AGRICULTURAL ECONOMISTS
ICAE
29th | Milan Italy 2015
UNIVERSITÀ DEGLI STUDI DI MILANO AUGUST 8 - 14
AGRICULTURE IN AN INTERCONNECTED WORLD

Potential Welfare Benefit of Millets Improvement Research to Inform Decision Making: Multi country - Economic Surplus model approach

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Abstract

In this paper a multi-regional international trade model using concepts of economic surplus and spillover effects is used to estimate the ex-ante measures of the relative economic benefits (accounting both direct and spillover benefits) to provide evidence for the research managers and policy makers in making judgment for prioritizing production domains for millets research focus and research resource allocation among regions and countries. The empirical results indicate that the highest expected benefits to millet research could be generated when research is focused on production domain of warm tropics dryland, 120-149 days but the high payoff production domains are different among regions. The contribution of spillover benefits to the total international benefits varies between 45 to 97% depending upon the research focus in different production domains. The analysis clearly brought out the insights to focus ICRISAT's millet research to achieve maximum benefits to generate greater impacts and research investment decisions.

Keywords: Priority Setting, millets production domains; spillover effects; multi-country trade model; economic surplus

JEL codes: O3; Q16; Q17

1. Introduction

International Agricultural Research Centers (IARCs) like International Crops Research Institute for the Semi-Arid Troics (ICRISAT) were established for developing dryland crop technologies, Natural Resource Management (NRM) technologies, methodologies and tools that would have wide applicability across agro eco-regions, intra-regions, inter-regions and countries to generate International Public Goods (IPGs). In the last four decades, ICRISAT's technologies of all mandate crops have achieved inter-regional spillovers from one region to another through various means such as networking, capacity development with national programs and south-south collaboration (Shiferaw et al. 2004). Given the situation, it is important to systematically quantify the spillover benefits from ICRISAT's own research and development investment to fully demonstrate the comparative advantages of international and national research system.

In this study, we estimate the expected international benefits from ICRISAT's millets research by fully accounting for spillover effects by adopting a methodology developed by ACIAR to estimate spillover benefits. This will inform and guide ICRISAT management in prioritizing millets production domain for achieving the highest benefits and to allocate scarce resources among different regions based on the potential welfare gains and impacts.

Millets cover about 35.2 million ha, worldwide (FAO 2012). The major pearl millet-producing countries in the world based on acreage are India, Nigeria, Niger, Sudan, Burkina Faso and Mali (Table 1). It is also grown in Senegal, Chad, Tanzania, Zimbabwe, Uganda, Angola, Zambia, Malawi, Botswana, Namibia, Ghana, Ivory Coast, Cameroon, Benin, Mauritania, Eritrea, Kenya, Pakistan and Myanmar. In India, pearl millet constitutes 58% of total millet production (Bantilan and Deb 2003), whereas finger millet's share is 27%. In China, pearl millet contributes only 10% of the total millet produced (FAO and ICRISAT 1996). In West Africa, pearl millet constitutes nearly 100% of the millet produced, while in ESA, both pearl millet and finger millet are the important crops among millets.

Pearl millet (*Pennisetum glaucum*) is a highly drought-tolerant cereal crop and an important food grain. It is generally grown as a rainfed crop on marginal lands with few inputs and little management. Pearl millet provides food for millions of people living in the arid and semi-arid regions of the Indian subcontinent and Africa. It is grown as a food crop in tropical Africa and India, with most of the production concentrated in Sahelian West Africa and north western India. These regions are characterized by high temperature; short growing season, frequent drought and sandy and infertile soils. In addition to its use for food, pearl millet has a high feed value for poultry and is a good source of energy and nitrogen in ruminant diets.

1.1. Millet Improvement at ICRISAT

ICRISAT began its millet research in four regions: Asia (1973), WCA (1976), South Africa (1984) and Eastern Africa (1984). The institute has contributed to the development of 163 cultivars, both hybrids and varieties as on 2012 (Kumara Charyulu et al. 2014). The focus has been on grain yield improvement and downy mildew resistance and exploratory research on ergot, smut and rust resistance and drought tolerance with equal emphasis being placed on the development of finished products (cultivars) and improved breeding materials/parental lines. Development of improved breeding and screening methodologies has been an integral part of applied research. In the 1970s, breeding of open-pollinated varieties (OPVs), rather than hybrids, was emphasized. In the African regions, development of OPVs continues to be the primary objective for several reasons that include:

I. seed production ease and economy,
II. relatively less vulnerability to diseases such as downy mildew, smut and ergot
III. Absence of an organized seed industry.

1.2. Enhancing pearl millet productivity

Pearl millet is mostly grown in marginal land with erratic rainfall, poor soil fertility with minimal input use in the dryland tropics. The productivity of this crop is very low because of the poor harvest index (HI) of landrace. This had been recognized as an important attribute requiring genetic improvement for increasing the grain yield potential of pearl millet. In addition, several biotic stress factors (diseases, insect pest and the root parasite *striga*) and abiotic stress factors (drought and salinity) were also recognized as important production constraints necessitating research for genetic improvement at ICRISAT.

With the establishment of ICRISAT, rapid progress has been made in breeding high yielding OPVs of pearl millet, which became possible due to the introduction of radically different and more productive germplasm from western and central Africa(WCA) region. This was exemplified by WC-C75 which was developed from the world composite introduced from Nigeria, and ICTP 8023 developed from an *iniari* germplasm introduced from Togo.

The sustainability of grain yield improvement through OPVs remained largely uncertain in India. The results from extensive All India Coordinated Pearl Millet Improvement Project (AICPMIP) trails demonstrated that hybrids, in general, had about 25% grain yield advantage over the improved OPVs of comparable height and maturity (Rai et al. 2006). It was this realization that reinforced increased attention on pearl millet hybrid program in India.

1.3. Spillover of millet technologies across regions

Shiferaw et al. (2004) reported that until 2001, about seven varieties developed at ICRISAT-Patancheru had been adopted and adapted in eight African countries. Prominent among these are WC-C75 (ICMV 1) and ICTP 8203 (Okashana 1). On the other hand, about 17 varieties developed by ICRISAT and/or NARS in Africa had been released in some 16 African countries. These include the downy mildew-resistant variety SOSAT-C88 developed through NARS ICRISAT partnerships in WCA and GB 8735 developed by ICRISAT-Niamey. These varieties have been released in a number of countries in the region, for instance a number of drought resistant varieties introduced in Southern Africa were developed by ICRISAT (Bulawayo) and by the regional NARS using ICRISAT's material. SMDV93032 (Okashana 2) ,which seems to have a good potential for expansion in to Eastern African countries would be a good example of such success stories of ICRISAT. It is important to note the limited transfer of millet varieties from Asia to WCA; perhaps because of the heavy disease pressure in this region, technologies from Asia were not found suitable. On the other hand, some of the varieties developed in Asia based on material from WCA have been adapted in ESA where disease pressure is relatively less. This indicates the crucial importance of strengthening the millet improvement program in WCA to develop alternative technologies best adapted to local biotic and abiotic constraints.

Moreover, several breeding populations, accessions and sources of resistance to diseases introduced from Africa have been utilized in breeding programs at Patancheru. Most notable are the 20,258 pearl millet germplasm accessions held in trust for the global community at ICRISAT. About 62% of these collections originated from Africa while 33% came from India. The germplasm is being screened for important agronomic traits (including pest, disease and drought resistance). The distribution of this germplasm worldwide represents one of the most important aspects of technology transfer and research spillovers in millets facilitated through ICRISAT.

2. Data and Methodology

2.1. The Multi-region Single commodity Economic Surplus Model

The calculations of potential economic welfare benefits from research investments have been used to prioritize research investment decisions and resource allocation. The study adopted and modified ACIAR's spillovers model that was developed by Lubulwa (1998) for the Australian Centre for International Agricultural Research (ACIAR) which focuses on and accounts for inter country and inter regional research spillover benefits[1]. The model builds on a framework that was earlier developed by Davis et al. (1987) to assist economic planners and research administrators in making choices about priorities in the allocation of agricultural research resources. The model explicitly incorporates spillover effects into an ex-ante analysis of aggregate commodity and regional priorities in agricultural research by the use of techniques that integrate economic surplus with international trade model. The framework allows differential probabilities of research success and ceiling adoption levels amongst commodities and regions to condition the expected economic benefits from alternative strategies. It is a partial equilibrium and multi-regional international trade model that integrates technical and economic model of research process to estimate consumer and producer surplus that results from agricultural research that reduces the cost of producing a commodity by proportion of its market price (Davis et al. 1987). This model allows spillover between production domains (also called as agro-climatic zones) and world price effects and the model handle one commodity at a time. The framework allows differential probabilities of research success and ceiling adoption levels amongst commodities and regions to condition expected economic benefits from alternative research strategies. The approach assumes that research investments and development of new technologies for an agricultural commodity leads to reduction in the unit costs, cost[2] of producing that commodity (Lubulwa et al., 2000). The millet research program at ICRISAT would improve the genetic potential to increase the productivity of the crops. In welfare economic terms, the yield-increasing effects of new technologies results in a shift of the supply curve (Norton and Davis 1981; Edwards and Freebairn 1984; Brennan and Bantilan 1999).

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[1] The net welfare benefits of agricultural research investments in a tradable commodity for its target country or region was influenced by the spillover of the effects of that research to other producing countries or regions with which the target regions competes for a share of the world market (Brennan and Bantilan, 1999). Edward and Freebairn (1984) demonstrated that the greater the extents of technologies adopted in non-targeting regions, the lower the net welfare benefits for the target region.

[2] The reduction in unit cost will be achieved by the farmer who adopted the new technologies either by producing more with same or less inputs, or producing the same level of outputs with fewer inputs.

The framework used in this study for the estimation of potential benefits of research using the economic surplus model also incorporates the following considerations:

- production and consumption levels of millets in different countries and regions;
- proportion of the millet produced in different production domains;
- climatic production domain to production domain applicability of millet technology;
- geographical research focus;
- country to country spillovers matrices;
- prices and elasticities;
- cost saving (unit cost reduction) due to research; and
- Discount rate (necessary because the analysis estimates benefits over a 30-year time period).

2.2. Use of Research Domains for Millets at ICRISAT

The research domains or agro-climatic zones concept has proven to be useful for setting priorities, targeting - identification of homogenous target countries in the same research domains, planning strategy, resource allocation, collaboration with researchers worldwide (Hartkamp et al. 2000; Maredia et al. 1996; Lubulwa et al. 2000). Homogenous research domains[3] for millets were developed in early 1990s (ICRISAT 1992) with the intention of helping breeders to manage genotype-environment interactions and to facilitate the transfer of technology from the region of origin to places where it might be beneficial/potential use. These domains were designed to reflect the main characteristics of group of countries in Africa and Asia (the main target regions of ICRISAT) according to the most important characteristics like length of growing periods, major production constraints and cropping pattern (ICRISAT 1992). Even though useful today, their accuracy has been limited (Mausch et al. 2012) because it did not take into consideration important indicators like temperature, latitude, crop suitability and distribution. Besides, there was an exclusion of other millet production regions around the world without which the estimation of global welfare benefits and spillover effects would be underestimated.

[3] The homogenous research domains for millets was drawn based on scientists and experts judgments on climate, length of growing periods and biotic and abiotic stress in the particular domains.

2.3. Refining and Defining Production domains of millets

Following the methodology developed by Mausch et al. (2012) to delineate the homogenous production domains, the spatial information on millet production (You et al., 2011); agro-climatic suitability based on agro ecological zones by FAO; land cover images to attribute only the crop land; and population density as a proxy to market access were used to define the 17 production domains of millets (Figure 1). The characteristics of production domains of millet have been given in the Table 2. The millets are cultivated under extremely harsh conditions of frequent drought, high temperatures, low and erratic rainfall, and infertile soils with poor water holding capacity. About 70% of the world millets are produced in the warm tropics dryland climate. Within warm tropics dryland climate, about 26.1% of millets are produced in the production domains with LPG between 120 to 149 days and 14.6% and 1.2% are produced in production domains with LPG between 90-119 days and 60-89 days respectively (Table 2).

Since millets are better adapted to driest and marginal soils than other cereals, about 2.9 and 2.6% of the millets are produced in production domains with LGP less than 60 days and deserts respectively (Table 2). Another 30% of the millets are produced in other production domains like warm tropics sub-humid, sub-tropical humid and dryland and temperate dryland.

2.4. Applicability of technology (C Matrix)

The specific crop technology developed from research investments for a particular production domain (or agro ecological zone) is likely to be of some relevance to the production of that same crops in other production domains (Lubulwa et al. 2000). Deb and Bantilan (2001) explained that the applicability of technology refers to a situation where a technology developed for one crop at a specific production domain can be adapted to improve the production efficiency of the same crop at other production location. However, the degree of applicability may vary across production domains mainly due to differences in production environments, agronomic, climatic, soil types and ecological factors.
Evenson (1994) defined the potential applicability for a crop technology as:

$$S_{IJ} = Y_{JJ}/Y_{IJ}$$

Where, Y_{jj} is the yield in production domain j of varieties developed for that production domain and Y_{ij} is the yield of the same group of varieties in production domain i.

The extent of the applicability—that is the size of S_{ij} depends on various biophysical and socioeconomic factors like agro ecological similarity between the originating and receiving region, local food tastes and preferences, factor prices, institutional factors (land tenure, intellectual property rights). The realization of potential spillover are also influenced by other factors such as historical and cultural links between countries, geographical proximity, complexity of the problem and other institutional factors (the research networks, and level of intellectual property rights).

This technical spillover of technology across production domains requires a focus on the effects of physical and biological differences between the production domains of millets. In the absence of the required multi location trail data across all the production domains of millets to estimate the performance of technology of all production domains, we used expert knowledge and judgment of several ICRISAT millet scientists to provide a value between 1 to 0 on the applicability[4] of a technology from one production domain to another production domain taking into consideration all the constraints (physical, biological, social, cultural and political) for technology spillovers between production domains.

2.5. Data and model parameters

The model uses production and consumption levels, production proportion of millets in specified production domain, climatic zone to zone applicability of technology, geographical research focus, country to country spillover matrices, prices, cost savings due to research, and a discount rate (Lubulwa et al. 2000). The following data were used to estimate the potential benefit of millets research:

2.5.1 Production, consumption, prices and elasticity data

Production and consumption data for millets was obtained from FAOSTAT. The data was collected for the period 1971-2009 but the model used the average production and consumption data for the period 2007-2009 in welfare estimation. The producer prices for millets (US$ per ton) were obtained from FAOSTAT. The average of 2005-07 producer

[4] Applicability matrix which shows how the varieties developed for one particular production domain is likely to outperform the best local variety in each of the other production domains.

prices has been used in the model. For a few countries, FAO doesn't report producer price. We therefore used regional average prices for the countries for which price data was not reported by FAOSTAT. The elasticity of demand and supply estimates for millets are based on the IMPACT model input data developed by IFPRI. For the countries that did not have elasticity of demand and supply estimates, estimates from countries from the same regions have been used.

2.5.2 Production proportions for millets

The production proportion for millets is the share of the total production in each production domain. These were estimated by overlaying production domains for millets map on the spatially distributed production map of millets developed by You et al. (2000)[5]. Using ArcGIS, the exact production of millets in each production domain was estimated and then the production was disaggregated by each country and production domains.

2.5.3 Research focus of countries

In ACIAR spillover model, research focus of individual country is one of the main determining factors for the estimation and distribution of benefits across countries. For the individual countries the research focus still reflects the national program's priorities across the different production domains (or distribution of research budget across different production domains). Since it is difficult to survey all countries to estimate their actual distribution of research efforts to individual production domains, it is assumed that the efforts are set according to the share of production from each production domain in the country. Thus the production proportions in each country are equivalent to the research focus in the model.

2.5.4 Country level strategic and applied research capacity

The strategic[6] and applied[7] research capacities of individual country are used to modify the estimated research benefits in ACIAR spillover model. In this study, the strategic or innovative research part was set to 100% as it was assumed that ICRISAT would conduct the

[5] http://MapSPAM.info (Accessed on 02-12-2012)

[6] Strategic research is defined as the research undertaken primarily to advance knowledge or to broaden the base of knowledge necessary for the solution of recognized practical problems.

[7] Applied research includes research that builds upon existing research results to develop appropriate technologies with a specific application.

innovative research and develop International Public Goods (IPGs) and therefore the national programs only need the capacity to adapt the technologies and disseminate the technologies to the farmers to adopt. Few indicators were used as a basis for the parameter estimates for applied research capacity for each country, i.e. FTE (Full Time Equivalent) scientists working for millet research in 1999 and 2011 and number of ICRISAT's pearl millet releases (Kumara Charyulu et al. 2014). After collating all the available data, we discussed with experts in pearl millets as well as impact assessment to arrive at the 0-1 scale required in the model. After a first round the 0-1 estimates were revisited by the team to discuss if the relativities are representative and it was concluded that some were to be adjusted to better reflect situation in the countries.

2.5.5 Ceiling adoption level

The ceiling adoption[8] level for a particular crop technology in a country depends mainly on the institutional and infrastructure conditions like input and output market structure, road network, awareness or knowledge about the technology to the farmers, and trader preferences on quality of the product etc. In the absence of databases across countries for ceiling adoption level especially for the African countries, the judgments of experts have been used to estimate the ceiling levels of adoption for these countries. In a stepwise procedure, these judgments were validated using multiple discussion rounds with experts from different regions and from different backgrounds (economists, breeders and agronomists) which were along the process backed with available data from various countries. This process thus ensured that the estimates were consistent across countries as starting from pure expert estimates, the rates given were cross-checked against available data for adjustments. Based on those adjustments the relativities were revisited and it was ensured that these were still in line with the real picture on the ground.

2.5.6 Other model parameters

The farm level impact assessment of pearl millet cultivars in India and a few African countries in 1990s revealed that the adoption of improved pearl millet cultivars contribute to unit cost reduction to the range of 18-59%. In this study a 10% unit cost reduction[9] as the

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[8] The ceiling level of adoption is defined as the maximum possible area under the new crop technology.

[9] The genetic improvement in millet increases the productivity, i.e. higher output for each level of inputs or higher yield for same level of inputs. The increase in yield with no increase in costs per hectare will reduce the cost per tons. This is referred to as the unit cost reduction for the proportionate change in productivity by adopting new technologies.

result of millets improvement research has been assumed for all countries and regions. The unit cost reduction is equal to 10% of the initial equilibrium price of millets in the countries and regions. The model used a 5% discount rate and it was assumed that the adoption pattern is the same for all the countries considered in this study. The benefits were estimated for a period of 30 year time horizon.

3. Results and discussion

The results of the quantitative analysis which are used to prioritize the target production domains of millets research to achieve greater welfare benefits have been presented in this section and have been discussed in three sub sections as follows:

3.1 Welfare benefits across production domains and regions

Since ICRISAT is an international research organization, it considers spillover research benefits along with direct benefits to prioritize the resource allocation and research investments. The expected benefits (with and without applicability[10] scenarios) from millet research with an assumption that ICRISAT would focus its research effort in single millet production domain at a time and annual benefits discounted at 5% per annum have been given in Table 3. The model results show that millet research which focused on the production domain -warm tropics dry lands, 120-149 days- would generate the highest expected welfare benefits over a 30 year time horizon of around $720.48 M among the 17 production domains delineated for millets. Since the production of millets is the highest in the production domain -warm tropics dry lands, 120-149 days- the benefits from research are also high. The results also show that when research is focused on production domain like deserts[11] it generates about $326 M benefits (Table 3) out of which 95 % of the benefits would accrue from spillover.

The regional disaggregation of benefits shows that the highest payoff production domain is not the same for all regions. In Asia, the warm tropics dry lands, 120-149 days is the highest payoff production domain with $479.85 M benefits but for WCA and ESA the highest payoff

[10] The without applicability scenario was run with off-diagonals of applicability matrix with 'zero' assuming that the technology developed for one production domain will not be suitable for other production domains. The total expected benefit from this scenario is the direct benefits to the production domain without any indirect or spillover benefits from the other production domains.

[11] The production domain desert is a very harsh environment with zero length of growing periods (LGP), high temperature, scanty rainfall and poor soil fertility which does not suit crop production. But about 2.6 % of millet is produced in this production domain. This is mainly because millet is the only crop which grows with very little water and withstands high temperature. So wherever little irrigation is available in the deserts of North Africa, Middle East countries, Pakistan and western part of India, millet is the only crop grown for food and fodder.

production domains is warm tropics dry lands, 90-119 days and warm tropics sub humid, >150 days with expected benefits of $242.42 M and $15.06 M respectively (Table 3). For ROW (include developed countries like Russia, China, Spain, and Hungary) the highest payoff production domain is temperate dry lands, 90-119 days with expected benefits of about $43.93 M.

Figure 2 presents the disaggregation of expected benefits into direct and indirect/spillover benefits when millet research is focused in one specific production domains. The results show that when millet research is focused on a production domain, the spillover benefits represent a high proportion of the aggregate total benefits in all the production domains excluding warm tropics dry lands, 120-149 days- about 56% of benefits are through direct benefits and 44 % accrue in the form of spillover effects. This is mainly because large share of millet production is from this particular production domain. However, for research focus in other production domains like deserts, only 5% of benefits are from direct benefits and about 95% from spillover benefits. This is mainly because of applicability of millet crop technology across production domains. If an international institute like ICRISAT fails to take these spillover effects into account in determining the expected benefits to research undertaken with focus on production domains, then their investment decisions might be based on the considerable underestimation of total benefits.

3.2 Benefits to individual countries for research focus on high payoff production domains

3.2.1 Region: Asia

Asia occupies half of the world millet area and is mainly grown in India, China, Pakistan, Myanmar, Nepal and Korea. Since India’s share alone is 30 % in the world millet area, the research focus on high payoff production domains - **warm tropics dry lands, 120-149 days-** would generate about $475.9 M of expected benefits with 10% reduction in unit cost and the current level of adoption and adaptive capacity (Figure 3). In the total world welfare benefits of $720.48 M, India’s share alone was around 66 % and about 99% of the Asian regional benefits.

3.2.2 Region: West and Central Africa (WCA)

The West and Central African (WCA) region has the largest area under millets in Africa (17 million hectares), of which more than 90% is pearl millet. The millets occupy major area in

Niger (6.9 m ha), Nigeria (4.1 m ha), Mali (1.5 m ha), Burkina Faso (1.4), Senegal (1.0 m ha) and Chad (1.0 m ha). When research is focused on highest payoff production domain - **Warm tropics dry lands, 90 - 119 days-** with 10 % unit cost reduction, the current level of adoption and adaptive capacity would generate highest welfare benefits in Nigeria ($145.4 M) followed by Niger ($34.1 M), Mali ($32.0 M), Burkina Faso ($20.7 M), Senegal ($4.3 M) and Chad ($3.9 M) (Figure 4).

3.2.3 Region: East and Southern Africa (ESA)

The ESA region occupies only 5% of the world millet area and is mainly grown in Sudan, Uganda, Tanzania, Angola, Namibia and Kenya. When research focus is on high payoff domain - **Warm tropics sub humid, > 150 days**-it would generate high welfare benefits in Uganda ($5.7 M) followed by Tanzania ($4.6 M), Sudan ($1.6 M), Kenya ($1.4 M) and Zambia ($0.5 M) (Figure 5).

3.3 Scenario Analysis: sensitivity of welfare benefits to important model parameters

The most important parameters to estimate the welfare benefits are the adaptive capacity and adoption rate of the individual countries. The present levels of these parameters are varying across countries and national and international initiatives are underway to improve these parameters. So in the future there is a possibility to improve the adaptive capacity and adoption rate in the target countries especially in the Sub Saharan Africa (SSA), where the current level of both adaptive capacity and adoption rate are very poor. To assess the magnitude of change in potential benefit when the real world moves to ideal world, we run different scenarios with the assumption that research will be conducted in the high payoff production and compare the current conditions (real world) with:

1. the adaptive research capacity where it reaches the maximum(Adaptive capacity = 1) and adoption rates remain the same;

2. the adoption rate which is maximum (Adoption rate = 1) and the adaptive research capacity remaining the same, and

3. The ideal world (Adoption = 1; Adaptive = 1).

The effect on the welfare benefits by change in different parameters presented by regions and individual countries is shown in the Figures 6 to 8.

Figure 6 reveals that in the ideal world situation the expected world benefits would be doubled (from $ 720.48 M to $1530.57M) compared to the real world which clearly shows that there is a lack of capacity to adapt research innovation which suits their production domains among countries and also there is poor adoption of technology by the farmers. The results also indicate that the Asian countries are already having higher adoption rate and also adaptive capacity, so there is no higher magnitude of change in welfare benefits but the untapped benefits are very high in WCA regions. The results show that when the adaptive capacity of research and adoption of technologies by farmers reaches the maximum level, the expected benefits would increase from $228.75 M to $826.05 M that is three folds higher than real world benefits (Figure 6), which is higher than that of the Asian region.

Even though the increase in both adaptive capacity and adoption rates resulted in higher welfare benefits in all countries in WCA and ESA region, there are differences in relative benefits of improving adoption rates and adaptive research capacities among the different countries. In some countries, improvement of adaptive research capacities results in more benefits than improvements in adoption rates. For example in Nigeria, the current capacity of adaptive research is low and adoption rate is slightly higher so the relative change in welfare benefits is higher for a change in adaptive capacity rather than adoption rate (Figure 7). But countries like Niger and Mali where ICRISAT has its hub of research operation for WCA and has better NARS collaboration and partnership in millet research the current level of adaptive capacity in those countries are high, so the relative change in benefits is high when there is a change in farmers adoption of technology which is currently low rather than adaptive capacity.

Figure 8 shows that in ESA too the untapped benefits are higher especially in countries like Sudan, Angola, Uganda, and Tanzania where the current levels of adaptive capacity and adoption rates are low. The results clearly indicate that to potentially tap the welfare benefits in SSA regions, along with millet improvement there is a need to invest in improving adaptive research capacity of the national crop improvement program and technology adoption by the farming community.

4. Conclusion

The aim of this paper is to quantify the expected welfare benefits taking into account both direct and spillover benefits of millet research from IARCs perspective by the application of rigorous welfare economics analytical tools using quantitative data. This study modified the ACIAR spillover model and attempted to quantify the expected welfare benefits by accounting spillover effects if ICRISAT were to develop millet technology as International Public Goods (IPG) and the countries adapt and adopt the technologies for different production domains. The analysis and insights are in turn used to develop priorities for millet research by identifying high payoff production domains and countries for targeting future millet research and to assist research managers and policymakers who are required to make judgments about the allocation of scarce research to achieve higher benefits.

In this paper, using the GIS application and available spatial data on AEZs, spatial production distributions, crop suitability map, etc., production domains of millets have been redefined. The new production domains map was used to estimate the production proportion of millets by country and production domains. The estimates of production proportion of millets clearly show that about 67% of the millets are produced in warm tropics dry lands environment which is characterized by low rainfall, high temperature, poor soil fertility and short length of growing periods. The applicability of crop technology across production domains developed with the help of millet breeders clearly shows the potential of millet to move across production domains which would have potential spillover benefits.

The analysis indicated that millet research could generate substantial benefits when the research focuses on production domain –warm tropics dry lands, 120-149 days. But to generate higher benefits in WCA and ESA, the millet research should focus in warm tropics dryland, 90-119 day and warm tropics sub humid, >150 days respectively. The contributions of spillover/indirect benefits to total benefits were substantial mainly because of applicability of millet technology across production domains. The results also indicate that by improving the adaptive research capacity and adoption rate, the SSA countries could reap substantially higher generate welfare benefits which are 3-4 times higher than the current level.

The following conclusions can be drawn from this study:

- The high payoff production domains are different among regions.
- The spillover benefits contribute substantially to total benefits that vary between 45 to 97% depending upon the production domain research focus. Without accounting for spillover, the total benefits for millets research could be under estimated.

- The results indicate that the contribution of different countries to total benefits could provide evidence for targeting countries and production domains to achieve higher benefits.
- The potential benefits could be increased by 3-4 times by improving the adaptive capacity and adoption of technology among farmers.

Acknowledgements

This work was undertaken as part of the CGIAR Research Program on Policies, Institutions, and Markets (PIM) led by the International Food Policy Research Institute (IFPRI). Funding support for this study was provided by CGIAR Research Program on Dryland Cereals (DC) and CGIAR Research Program on Policies, Institutions, and Markets. This paper has gone through the standard peer review procedure of 29th International Conference of Agricultural Economists (ICAE), Milan, Italy.

The opinions expressed here belong to the authors, and do not necessarily reflect those of PIM, DC, IFPRI, ICRISAT or CGIAR.

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Tables and Figures

Table 1 Area, Production and Productivity of millets in Asia and Africa, 2008-10

COUNTRY	Area ('000 ha)	Production ('000 tons)	YIELD (kg/ha)	% Share of pearl millet to total production*
ASIA				
Afghanistan	10.0	25.3	2533.3	
India	11332.5	14597.7	1288.1	58
Myanmar	207.8	252.6	1215.5	85
Pakistan	497.8	413.3	830.3	97
Yemen	116.4	111.6	958.7	100
Sri Lanka	6.2	8.6	1384.5	
Bhutan	4.0	7.8	1924.0	
Nepal	266.6	389.4	1460.4	
Bangladesh	30.6	23.3	762.5	
China	786.2	1760.1	2238.6	10
Subtotal	13258.2	17589.7	1326.7	
WESTERN AFRICA				
Benin	38.2	42.9	1122.9	100
Burkina Faso	1398.1	1446.7	1034.8	99
Cote d Ivorie	59.9	57.4	959.1	85
Cameroon	51.1	88.4	1731.7	100
Central African Region	9.5	13.3	1403.7	87
Chad	971.4	782.8	805.9	100
Gambia	142.6	172.6	1209.8	95
Ghana	181.8	257.1	1414.0	100
Guinea	324.4	365.1	1125.3	95
Guniea Bissau	22.1	32.6	1478.4	100
Nigeria	4134.4	8721.2	2109.4	100
Niger	6835.1	4275.0	625.4	98
Senegal	989.5	873.5	882.8	100
Sierra Leone	27.2	28.7	1056.2	100
Togo	72.4	64.4	889.4	100
Subtotal	15257.6	17221.7	1128.7	
EASTERN and SOUTHERN AFRICA				
Angola	151.5	88.2	582.2	80
Botswana	5.6	1.7	299.0	100
Malawi	39.8	27.7	696.6	40
Mozambique	49.4	26.2	530.9	80
Namibia	234.6	52.4	223.4	100
Sudan	2235.5	1006.6	450.3	100
Tanzania	317.3	216.8	683.2	
Zambia	47.2	50.9	1077.5	40
Zimbabwe	212.1	57.3	270.0	70
Subtotal	3293.0	1527.7	463.9	
WORLD	35227.3	41514.3	1178.5	

*percentage share of pearl millet to the total millet production is taken from ICRISAT/FAO (1996) and relates to 1992-94. Source: FAOSTAT (2012)

Table 2 Characteristics of Millets Production domains

S. No	Production Domains (PD)	PD Characteristics, Climate and Length of Growing Period (LGP)	Production ('000 tons)[1]	Production share (%)	Major Countries	Major Constraints
1	**PD1**	Deserts	654.08	2.6	Pakistan, Sudan, Mai, Niger, Burkina Faso, Saudi Arabia, Iran, Iraq, Yemen, Morocco, Libya, Australia	Heat and drought, head caterpillars, *striga*
2	**PD2**	Warm tropics drylands, < 60 days	730.23	2.9	Chad, Niger, Nigeria, Mali, Sudan, Zimbabwe, Australia	Downy mildew, drought
3	**PD3**	Warm tropics drylands, 60 - 89 days	2842.61	11.2	Chad, Mali, Niger, Kenya, Namibia	Downy mildew, drought, photoperiod sensitivity
4	**PD4**	Warm tropics drylands, 90 - 119 days	3687.02	14.6	India, Cameroon, Chad, Mali, Niger, Nigeria, Senegal, Burkina Faso, Namibia, Zimbabwe	Downy mildew, smut, Need for reduced photoperiod sensitivity
5	**PD5**	Warm tropics drylands, 120 - 149 days	6600.22	26.1	India, Cameroon, Chad, Benin, Gambia, Mali, Nigeria, Senegal, Burkina Faso, Angola, Mozambique, Zimbabwe, Zambia	Downy mildew, smut, drought
6	**PD6**	Warm tropics drylands, > 150 days	3098.35	12.2	India, Cameroon, Chad, Gambia, Angola, Malawi, Tanzania, Zambia	Drought, stem borer and *striga*
7	**PD7**	Warm tropics sub humid, > 150 days	2716.09	10.7	Myanmar, Cameroon, Central African Republic, Benin, Ghana, Guinea, Togo, Malawi, Mozambique, Uganda, Zambia	Drought, stem borer
8	**PD8**	Subtropical drylands, > 150 days	355.70	1.4	Nepal, Pakistan, Argentina, Mexico	Stem borer, ergot
9	**PD9**	Subtropical Humid, < 60 days	165.01	0.7	Pakistan, Zaire, Ivory Coast, Mexico	
10	**PD10**	Subtropical Humid, 60 - 89 days	334.63	1.3	Pakistan, Ethiopia, South Africa	Drought and heat
11	**PD11**	Subtropical Humid, 90 - 119 days	583.25	2.3	India, Pakistan, Bangladesh, Bhutan, South Korea, Australia	Downy mildew, drought and heat
12	**PD12**	Subtropical Humid, 120 - 149 days	695.97	2.7	India, Pakistan, Bangladesh, Bhutan, South Korea, South Africa, Australia	Downy mildew, drought and heat
13	**PD13**	Subtropical Humid, > 150 days	342.55	1.4	Nepal, Australia	Downy mildew, drought and heat
14	**PD14**	Temperate drylands, < 60 days	281.89	1.1	China, Hungary, Japan, Spain, Russia	Stem borer, ergot
15	**PD15**	Temperate drylands, 60 - 89 days	537.17	2.1	China, Romania, USA, Russia	Stem borer, ergot
16	**PD16**	Temperate drylands, 90 - 119 days	1293.96	5.1	China, Russia, Spain	Stem borer, ergot
17	**PD17**	Temperate Humid, > 150 days	411.76	1.6	China, North Korea, Australia	Stem borer, ergot

Note: [1]The SPAM (2010) spatial distributed production map of millets is used to estimate the production level in each PD

Table 3 Total present value (PV) welfare benefits (with and without applicability) to each of the production domains from millet research resulting in 10% unit cost reduction (in M US$)

S No	Production Domains	Production ('000 tons)	Total	ICRISAT –focus[a]	Asia	WCA	ESA	ROW[b]	Total	ICRISAT -focus	Asia	WCA	ESA	ROW
			With applicability						Without applicability					
1	Warm tropics drylands, 120 - 149 days	6600.22	720.48	718.64	479.85	228.75	10.04	1.84	405.59	405.52	314.00	89.57	1.95	0.06
2	Warm tropics drylands, > 150 days	3098.35	676.33	673.69	464.53	197.83	11.34	2.63	199.97	199.90	161.37	36.06	2.46	0.07
3	Warm tropics drylands, 90 - 119 days	3687.02	636.68	634.83	383.40	242.42	9.02	1.85	145.69	145.61	45.33	99.10	1.19	0.08
4	Warm tropics drylands, 60 - 89 days	2842.61	559.39	557.10	324.51	222.81	9.78	2.29	112.70	112.68	35.92	75.44	1.32	0.02
5	Warm tropics sub humid, > 150 days	2716.09	549.04	546.75	376.62	155.07	15.06	2.29	127.29	127.24	82.05	33.62	11.57	0.05
6	Warm tropics drylands, < 60 days	730.23	472.30	460.64	272.99	179.42	8.23	11.66	23.94	23.94	2.04	21.22	0.68	0.01
7	Subtropical drylands, > 150 days	355.70	374.10	371.98	255.93	108.10	7.95	2.12	11.34	10.60	10.60	0.00	0.00	0.74
8	Deserts	654.08	326.93	321.99	194.37	120.91	6.70	4.94	18.05	13.27	5.41	6.01	1.85	4.78
9	Subtropical Humid, 120 - 149 days	695.97	290.18	279.98	246.36	27.98	5.64	10.20	59.21	58.72	58.71	0.01	0.00	0.49
10	Subtropical Humid, > 150 days	342.55	289.55	281.25	239.28	34.93	7.04	8.29	23.26	22.27	22.25	0.00	0.02	0.99
11	Subtropical Humid, 90 - 119 days	583.25	218.33	211.04	190.35	17.61	3.08	7.29	49.16	48.69	48.68	0.01	0.01	0.47
12	Subtropical Humid, 60 - 89 days	334.63	173.56	168.06	151.26	13.98	2.82	5.50	26.80	26.77	26.76	0.00	0.00	0.03
13	Temperate drylands, 90 - 119 days	1293.96	167.60	123.67	123.66	0.01	0.01	43.93	91.97	66.58	66.58	0.00	0.00	25.38
14	Subtropical Humid, < 60 days	165.01	153.53	148.13	129.17	16.08	2.89	5.39	12.88	12.75	12.75	0.00	0.00	0.13
15	Temperate drylands, 60 - 89 days	537.17	141.45	101.60	97.22	4.25	0.14	39.85	40.73	27.95	27.95	0.00	0.00	12.77
16	Temperate Humid, > 150 days	411.76	133.29	102.32	102.31	0.01	0.01	30.97	33.85	29.73	29.73	0.00	0.00	4.12
17	Temperate drylands, < 60 days	281.89	124.40	86.57	77.81	8.49	0.27	37.83	16.45	0.36	0.36	0.00	0.00	16.09

Note: [a] Total welfare benefits in Asia, West and Central Africa (WCA) and Eastern and Southern Africa (ESA) countries where ICRISAT focuses its research investments; [b] ROW – Rest of the world

Source: Authors calculation

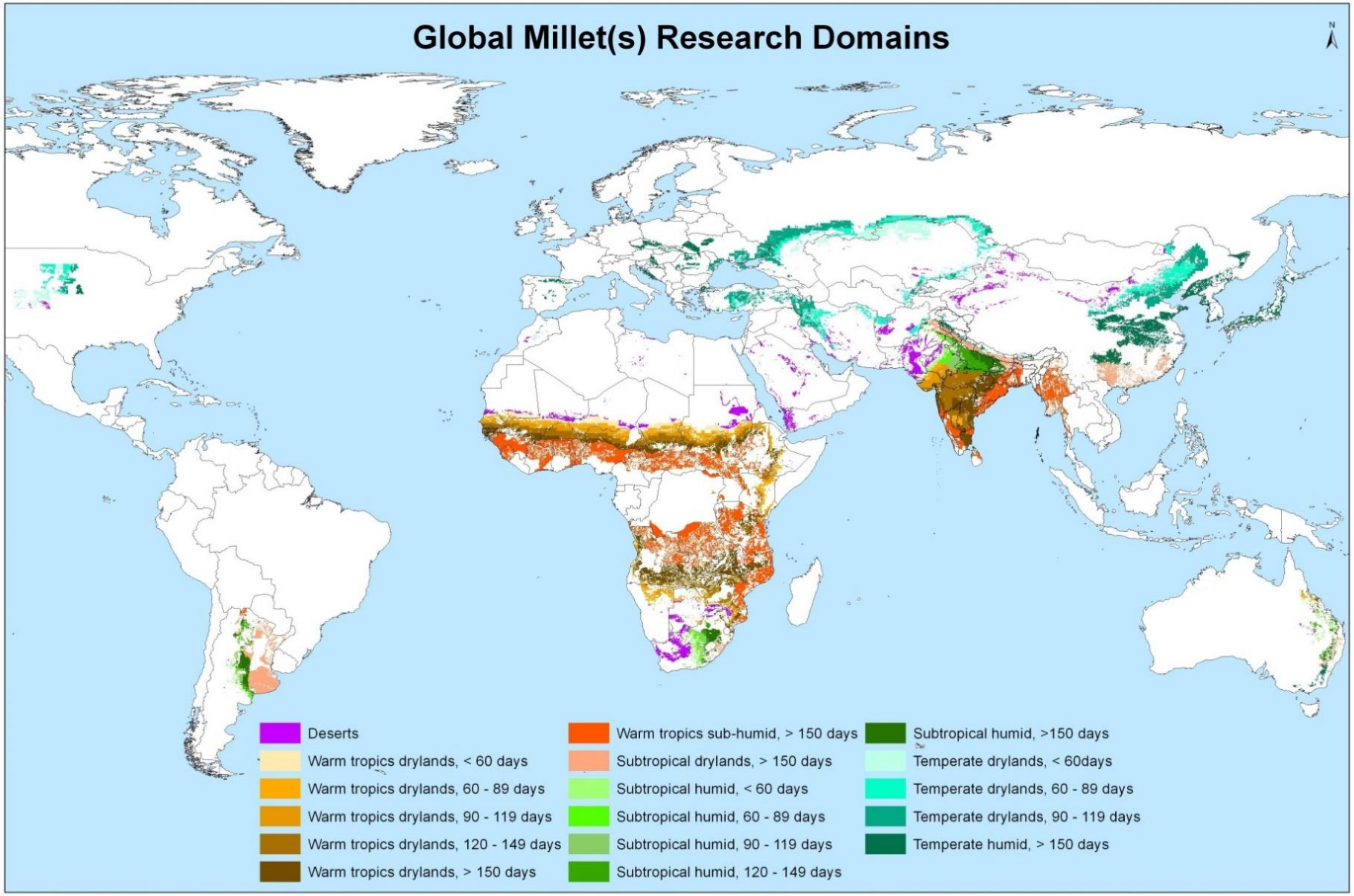

Figure 1 Global Millets Production Domains

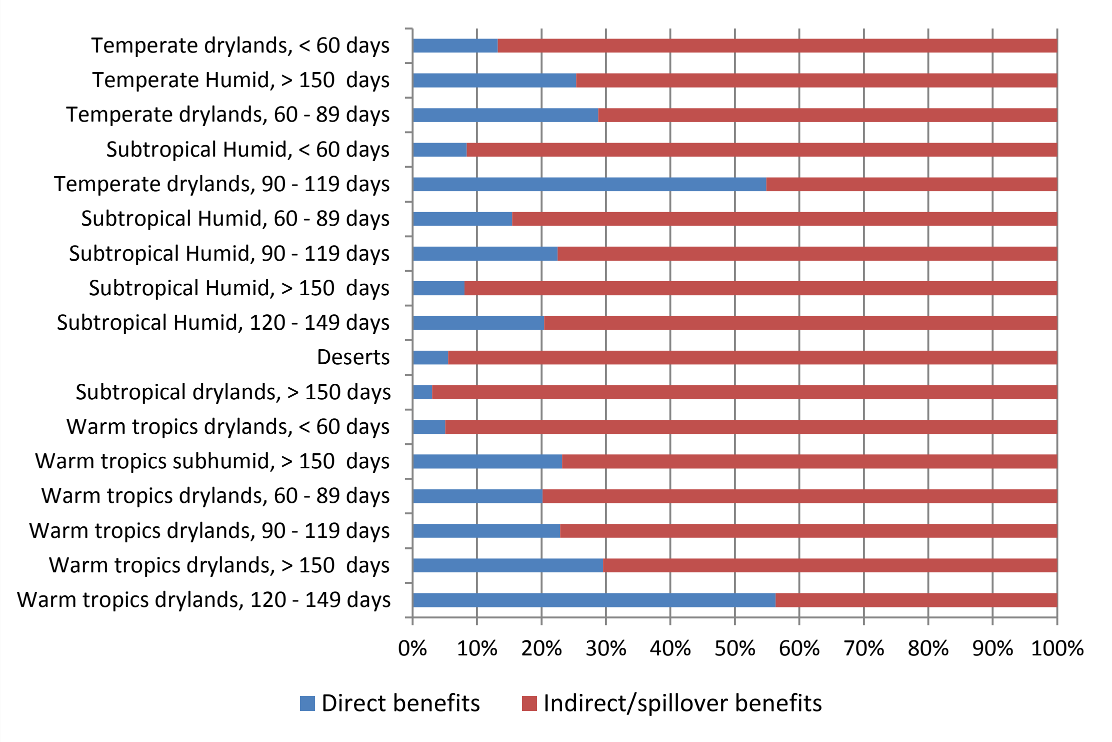

Figure 2 Direct and indirect (spillover) benefits (in %) to each of production domains from millet research resulting in 10% unit cost reduction (in M US$)

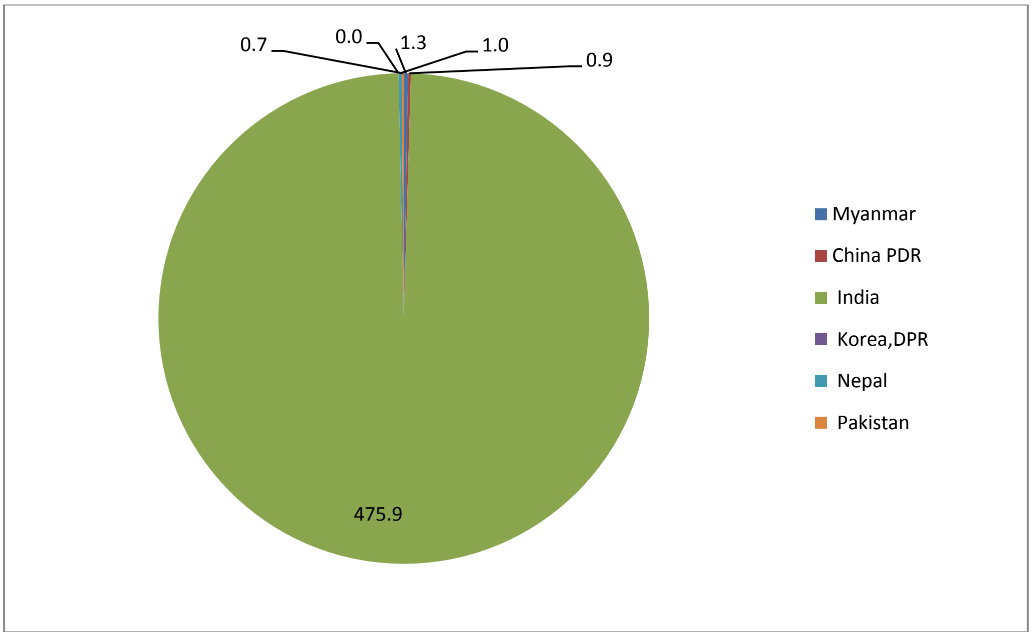

Figure 3 Total welfare benefits (in M US$) in Asian countries (Research focused in highest payoff PD - Warm tropics drylands, 120 - 149 days)

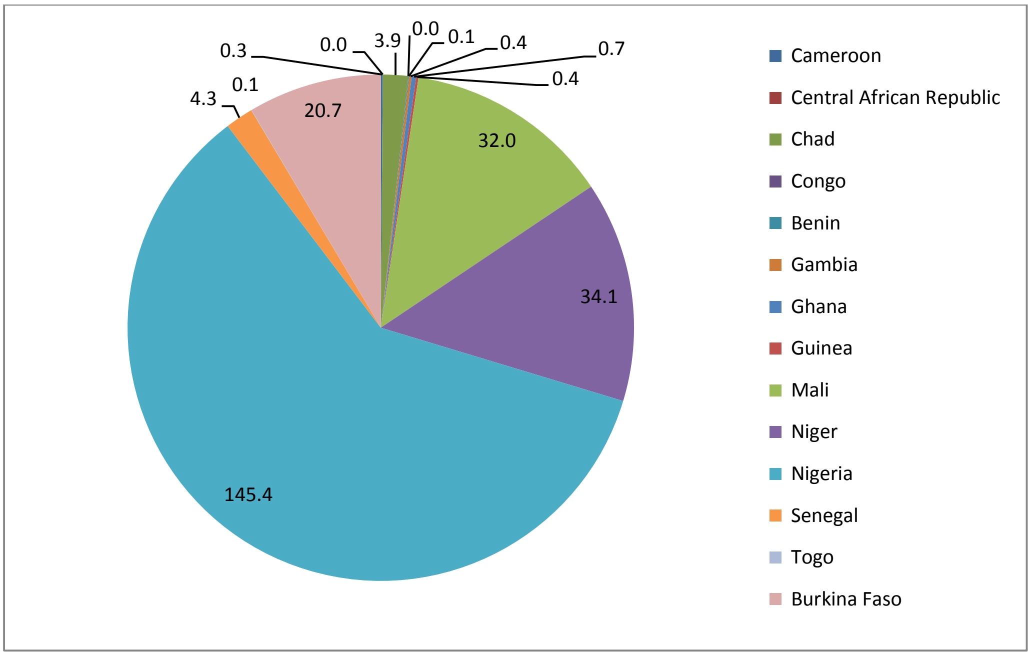

Figure 4 Total welfare benefits (in M US$) in West and Central African countries (Research focused in highest payoff PD - Warm tropics drylands, 90 - 119 days)

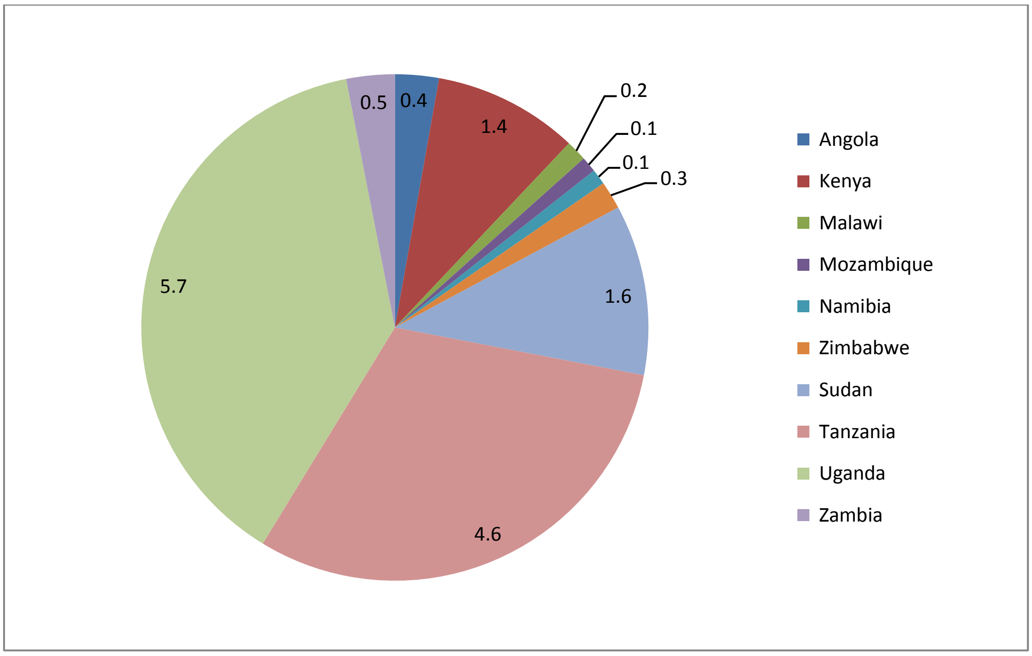

Figure 5 Total welfare benefits (in M US$) in East and Southern African countries (Research focused in highest payoff PD - Warm tropics sub humid, > 150 days)

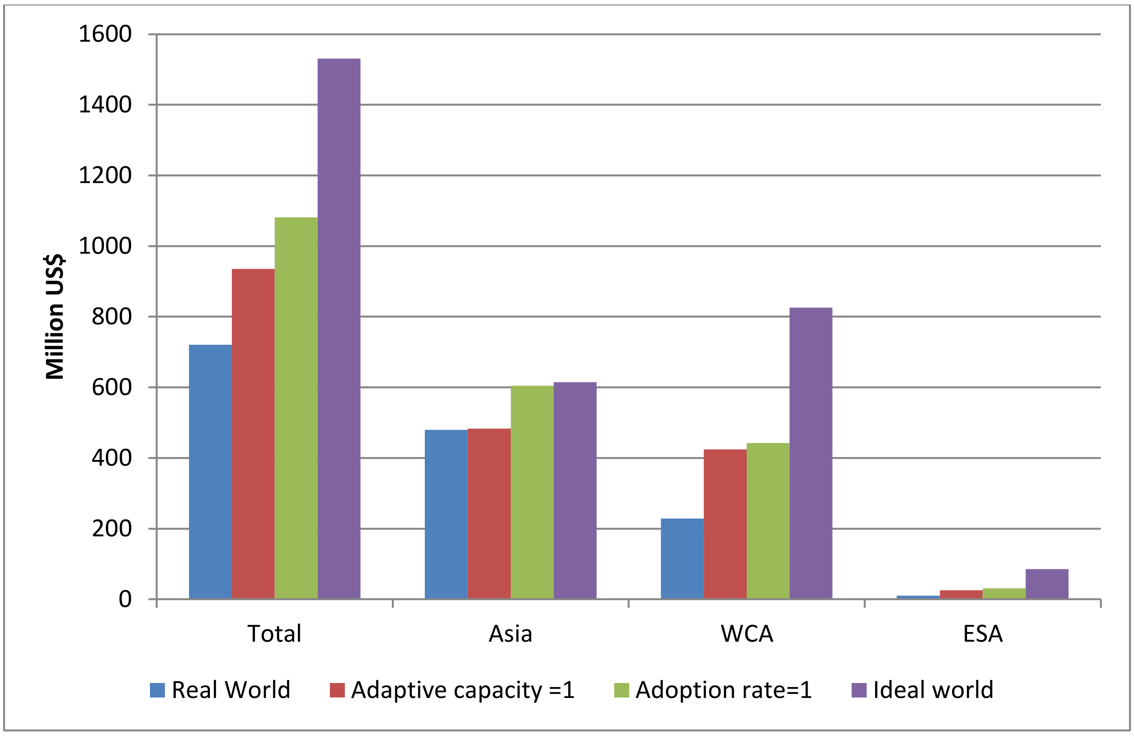

Figure 6 Welfare benefits (in M US$) by regions under different scenarios (Targeting the highest payoff production domain - Warm tropics drylands, 120 - 149 days)

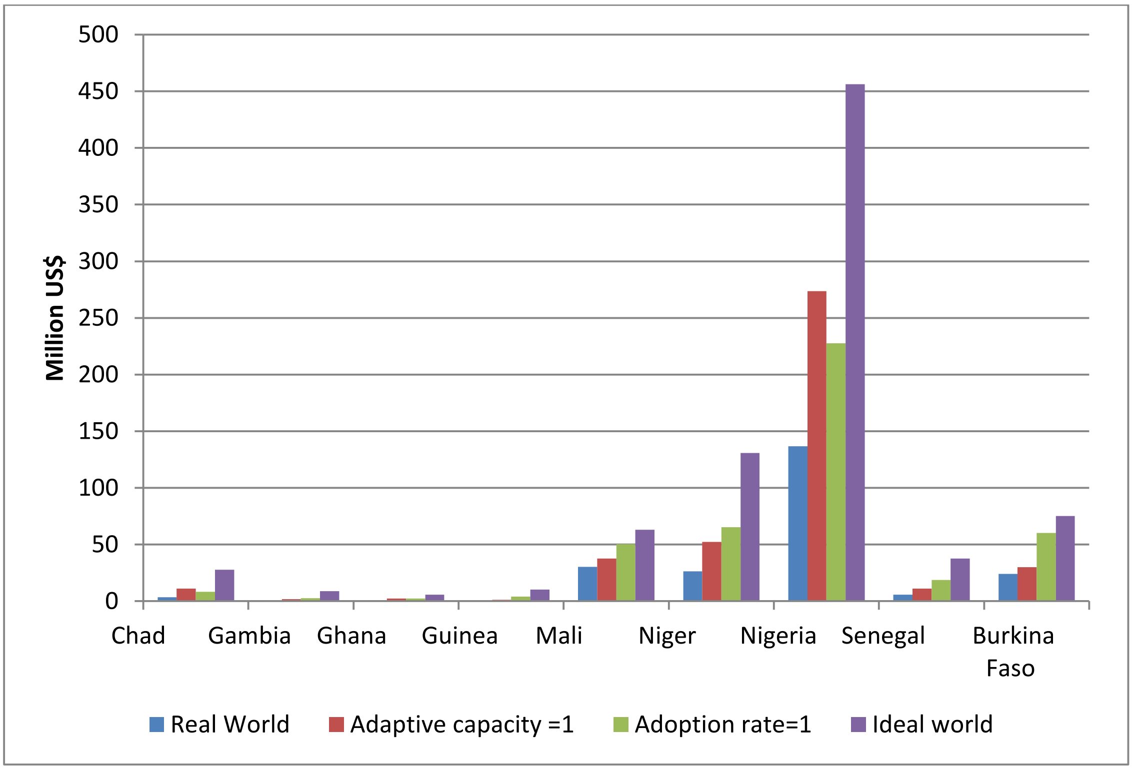

Figure 7 Welfare benefits (in M US$) by countries in WCA under different scenarios (Targeting the highest payoff production domain - Warm tropics drylands, 120 - 149 days)

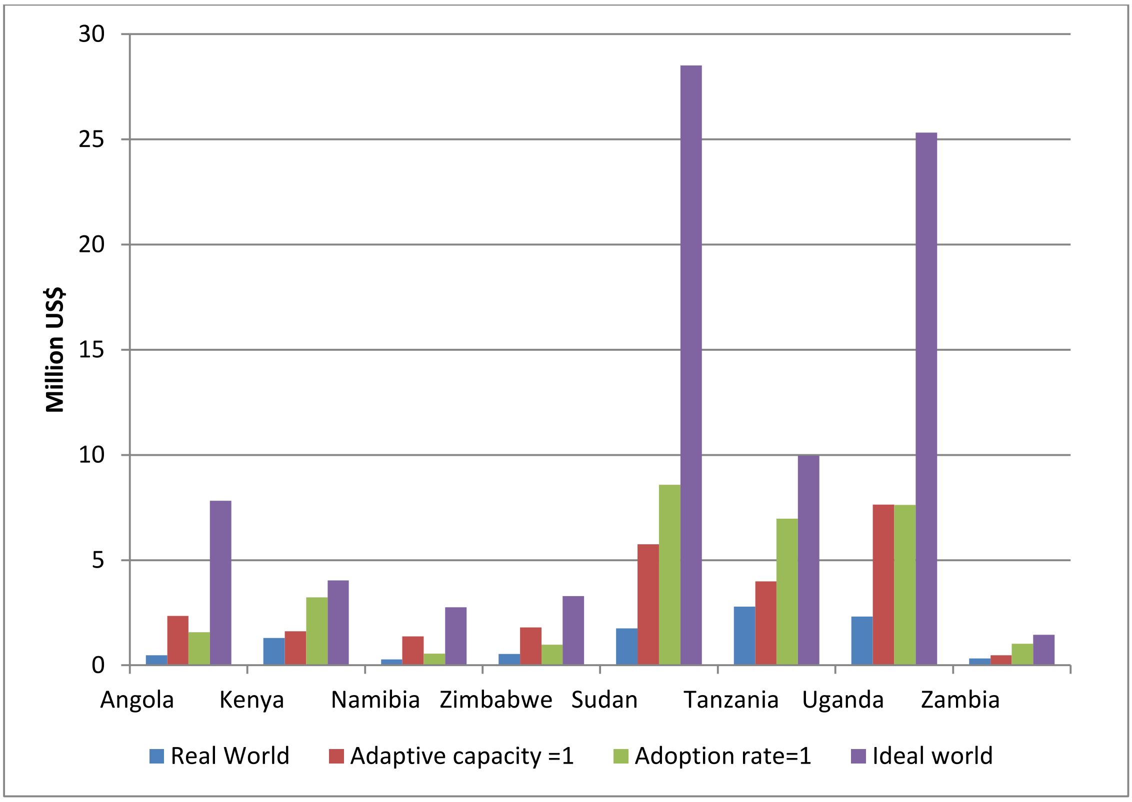

Figure 8 Welfare benefits (in M US$) by countries in ESA under different scenarios (Targeting the highest payoff production domain - Warm tropics drylands, 120 - 149 days)