International Cooperation and Partnerships in Agricultural Research and Development: A Perspective[1,2]

Executive Summary

International cooperation in Agricultural Research and Development (ARD) was firmly established when the Consultative Group for International Agricultural Research (CGIAR) was formed in 1971, following focused deliberations in the 1960s. Global support and funding for CGIAR reached its peak during the first decade of the 21st century. Over the past decade, however, both bilateral and multilateral support for ARD have been declining, despite evidence that the rate of return on investment in ARD was high and international cooperation had helped reduce hunger and poverty in developing countries. In this paper, the authors (1) trace the evolution of international cooperation in ARD, (2) list some examples of the impact made and lessons learned, particularly in key areas of crop-based ARD, and (3) provide some perspectives that justify the need for increasing support, with enhanced funding, for international ARD to meet the global sustainable development goals (SDG).

International cooperation has helped establish a strong knowledge base on global climate change. This helped in reaching international agreements on efforts to counter the trend of global warming and other climatic disasters. Through adaptation and mitigation, countries have attempted to maintain food production and supply systems at an optimal level. But such cooperation appears to be declining, and it will require renewed cooperative efforts and funding support, so that even poor countries will be able to carry out the research and mitigating actions needed, and thus contribute to SDG 13 (climate action).

International agricultural research on land, soil, and water management has been mostly strategic, focusing on developing scientific concepts and principles, processes, and research methodologies. Process-oriented approaches at the watershed scale, understanding linkages and interactions of management of land and water on agroecology, and understanding the process of land degradation, etc., have contributed to achieve SDG 15 (sustainable use of terrestrial ecosystems). The innovative integrated watershed model is increasingly being used as a platform for natural resource management and also for launching broader livelihood programmes. Studies on soil management have led to the development of usable methods and tools to improve soil productivity and enhance sustainability. International cooperation and alliances on soil and water management have also facilitated exchange of improved technologies across partner countries.

Plant genetic resources_(PGR) are essential for crop improvement and crop diversification. Cooperation, supported by international funding, has resulted in large

---

[1] Prepared by Drs. SV Raghuram Shetty, V Ramanatha Rao, CL Laxmipathi Gowda, MVK Sivakumar, MJ Vasudeva Rao, and AKS Huda. The authors acknowledge with thanks the input received from Dr. Hari J Krishna and the editorial guidance and help provided by Dr. DR Mohan Raj.

[2] The document is based mostly on the direct experiences of the authors, and thus focuses primarily on plant-based agriculture.

assemblies of PGR in national and international genebanks, along with the protocols for their conservation and use. In recent years, however, both funding and international cooperation in PGR have drastically reduced, endangering continued conservation and use of PGR. Hence, the funding situation needs to be redressed to make a comeback in PGR conservation, which contributes directly to UN SDG15 and indirectly to other SDGs.

The 'Green Revolution' would not have been possible without the widespread international exchange of improved high-yielding varieties, which thus became available to many developing countries. International collaboration in crop improvement involved the sharing of early and advanced generation breeding lines and improved varieties. There are innumerable examples of the significant and positive impacts of international collaboration on crop productivity and production in many developing countries, and of how that helped in fighting food shortages and malnutrition. The shining example is the 'Green Revolution' in India, Pakistan, and other countries in South and Southeast Asia. Hence, multilateral donors need to up the ante for enhanced funding for crop improvement, which is a long-term research activity that contributes to SDG 1, 2, and other goals.

Seed systems are institutional mechanisms through which farmers access good quality seed of crop varieties. Both bilateral and multilateral international collaborations have contributed to improving seed systems in developing countries. Committed stewardship, often through regional partnerships and networks, has helped in improving seed systems in many countries. The experience of India may have relevance to African and other developing countries, along with assistance from the private sector seed companies from Asia, Europe, and the US. Developing robust seed systems, through public-private partnerships, within reach of the farmers, especially smallholders, should be the foundation for future global food and nutritional security and seed trade, contributing to SDG 1, 2, and 15.

Integrated farming systems (IFS) research has focused on providing a scientific basis to improve different components of farming systems. Outputs from such holistic, multidisciplinary research have had multiplier effects, resulting in productivity and environmental benefits from the adoption of improved cropping/farming systems in different agroclimatic regions. Such systems research has helped many developing countries to increase and stabilize their agricultural production, by developing sustainable location-specific technologies. Studies on agroclimatic characterization and simulation modelling have provided a sound basis for designing and disseminating improved systems. IFS research has demonstrated how the global challenges of hunger, poverty, and degrading natural resources can be tackled together by utilizing multidisciplinary approaches. Thus, there is a need to continue to support international cooperation in this important facet of ARD to meet the targets set under many SDGs.

Strengthening national agriculture research systems (NARS) and institutional infrastructures in developing countries has been at the heart of international cooperation. Capacity building for developing country personnel, with support from advanced institutions in Europe and the United States and later with CGIAR, alongside networking of researchers with similar interests, has strengthened human resources. Various avenues of cooperation, including regional and international networks, flourished with support from the international community. The collaboration between India and some African countries (India-Africa partnership) in human resources development is a recent example of South-South Cooperation. However, strengthening of national research systems and networking of NARS needs continued technical and funding support.

The needs of future global food systems and associated challenges, along with recent shifts in donor priorities, call for increased international cooperation and partnerships in ARD. Sustainable agriculture requires smart agriculture, which is imperative for the long-term survival of human beings on planet Earth. There is an urgent need to revive, rejuvenate, and strengthen international cooperation and partnerships in agricultural technology management, particularly to address multi-dimensional global challenges, including climate change, poverty, hunger, public health, education, economic growth, livelihood security, and environment (including biodiversity, land, and water).

In conclusion, as agriculture and environment cut across most of the SDGs, continued global cooperation and partnerships in ARD are crucial to achieving the desired development goals.

1. Introduction

In September 2015, the international community, under the aegis of the United Nations (UN), endorsed a universal agenda, entitled 'Transforming Our World: the 2030 Agenda for Sustainable Development', and set for itself goals that have come to be known as the Sustainable Development Goals (SDGs). Specifically, SDG 17 calls for strengthening the partnerships for sustainable development through South-North, South-South, regional, and international cooperation in science, technology and innovation, and knowledge sharing. The emphasis is on promoting the development, transfer, dissemination, and diffusion of environmentally sound technologies in developing countries.

International cooperation in agricultural research and development (ARD) existed even during the colonial era. Britain and France encouraged their higher educational institutions to assist colonies in Asia and Africa in establishing agricultural education, research and development institutions. In India, for example, the Indian Agricultural Research Institute was established as early as 1911. Similarly, the colonial powers (such as Britain, France, Portugal, and Spain) were involved in developing ARD in their host countries in Africa, Asia, and Latin America, but they focused mainly on cash crops and commodities which supported their own economies. After independence, most of the former colonies continued their collaboration with the colonial powers, as well as with other countries. For example, a strong ARD institutional infrastructure was established in India, with considerable support from the United States Agency for International Development (USAID) and private foundations, such as the Rockefeller and Ford Foundations.

During the 1950s and 1960s, multilateral collaboration was initiated throughout the developing world, mainly through the United Nations (UN) agencies. However, it was with the establishment of the Consultative Group for International Agricultural Research (CGIAR) in 1971 that multilateral collaboration in ARD took stronger roots, through CGIAR's network of International Agricultural Research Centers (IARCs). The impact of IARCs in developing and diffusing improved agricultural technologies for alleviating poverty, hunger, and environmental sustainability is now well known.

Collaboration and partnerships among countries and institutions, aimed primarily at enhancing ARD, flourished for some decades, with funding for the CGIAR peaking in 2008. But more recently, from about 2014, funding for the CGIAR has been in decline, affecting international collaboration and partnerships for ARD. Over the years, such partnerships have declined for various reasons; most important among those is the fall in food prices across the globe, diverting donors' attention (see https://www.devex.com/news/are-donors-pulling-back-on-agriculture-research-funding-88276). Besides, some donor countries, for their strategic reasons (like enhancing their soft power and ability to influence), have diverted interest and funds from multilateral to bilateral programmes.

Unfortunately, this decreased support has come at a time when there is a greater need for increased and sustainable food production (significantly by 2050) to avoid global hunger and malnourishment and to reduce poverty. That urgent need can only be addressed by reviving international cooperation and partnerships in ARD through multilateral, north-south, and south-south partnerships. As the rate of return on investments in ARD is significant (estimated up to 10 times by CGIAR), it should also provide a strong economic rationale for increasing financial support for such international cooperation in ARD (Fuglie and Heisey, 2007).

In this paper, based on our collective experience, we attempt to address some priority key areas in international ARD, along with some lessons learned, provide some suggestions for the future, and highlight the need for increased funding and support for international efforts.

2. Key Areas of International Agricultural Research and Development

International cooperation in ARD during the last few decades has focused on a wide range of areas of agriculture, which include basic, strategic, applied, and adaptive research and technology transfer activities. Institution building activities in the developing countries were also part of such cooperative efforts. The major goal of international cooperation during the early years was to achieve global food security; it later included nutritional security and poverty alleviation, and it has more recently being gradually extended to include sustainable development, which focuses on natural resource management. In this section, we highlight the key areas/themes of which have received more attention in recent years, along with some examples of their impact, as well as the lessons learned. Resume here

A. Climate Change, Adaptation, and Mitigation

International cooperation on monitoring the agroclimatological resource base, together with studies on the characterization of the agroclimatic environment, has provided a sound basis for the designing and transferring of agricultural technologies throughout the world. International climatologists and agronomists, together with the National Meteorological Services and the World Meteorological Organization (WMO), have focused on a wide array of research areas, such as climatic resource characterization, variability in climatic factors like rainfall, temperature, studying the processes and effects of climate change, and methods for mitigation and adaptation to climate change, etc. Since much of what we know today about climate change is the result of international cooperation, we briefly summarize the knowledge gained thus far, to indicate the imperative need for continued cooperation in efforts aimed at mitigation and adaptation to such change.

Knowledge base: Climatological studies, carried out via extensive international collaboration, have established a strong knowledge base on global climate and climate change. For example, earlier studies had shown that the earth's climate can change dramatically and that human activities contributed to global warming. More recent studies have shown that the global warming scenario is very likely (>95% probability) and mainly a result of human activity at an accelerated rate since the mid-20th century (IPCC, 2013); most of the change has occurred in the past 40 years, with the six warmest years on record occurring since 2014. Human activities are estimated to have caused approximately 1.0°C of global warming above the pre-industrial level (IPCC, 2018); that is likely to reach 1.5°C sometime between 2030 and 2052 if the current rate of increase continues.

The knowledge base has also helped document the process and identify the major causes of global warming. For example, atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and other greenhouse gases are increasing steadily since 1750 due to human activity (IPCC, 2013). Over the last century, the burning of fossil fuels (like coal and oil) has increased the concentration of atmospheric carbon dioxide (CO_2). Carbon dioxide from human activity is increasing more than 250 times faster than it did from natural sources after the last Ice Age (Gaffney and Steffen 2017). The studies have warned that the future trajectory of $C0_2$ increase will depend on what we do as a society—indicating that we need to aggressively reduce emissions; we could stay below 500 ppm, maybe lower. To a lesser extent, the clearing of land for agriculture, industry, and other human activities has increased the concentration of greenhouse gases; mitigating action will now depend on the extent of international cooperation.

Extreme events: The cooperative studies have also established that extremes in weather and climate, both in number and strength, cause most of the problems. Changes in several such extreme events (drought, extreme heat, extreme precipitation, etc.), have been observed since about 1950. Over the past 100 years, fifteen of the hottest summers have occurred since 2000 (IPCC, 2018). Thus, the world is already experiencing climate change-induced impacts, such as rising sea levels, changing rainfall patterns, increased droughts, and more erratic storms which negatively affect local crop production, especially in subsistence sectors at low latitudes. Annual losses from weather disasters frequently run into hundreds of billions of dollars. In total, weather-related natural disasters have caused losses of about US$ 4,200bn since 1980 and killed nearly a million people (https://www.munichre.com/topics-online/en/climate-change-and-natural-disasters.html). Therefore, to predict and reduce losses due to such extreme weather events, continued international cooperation is imperative.

Adaptation: With the adoption of UN 2030 Agenda for Sustainable Development (SDG 13: Climate Action) and the Paris Agreement at the 21st Session of the Conference of the Parties (COP-21) to the United Nations Framework Convention on Climate Change (UNFCCC) in 2015, the global community took a significant step towards tackling climate change. The Paris Agreement represents a major milestone in international efforts to combat climate change, and it sets out a global action plan. Recently, international cooperation in agroclimatological research has paid attention to studying the effects of climate change on agricultural production and developing solutions that can help in mitigation and adaptation to such change. Since the atmosphere is shared by all, these actions will typically have long-term, global benefits. There is a need to enhance international cooperation in issues such as increasing the efficiency of using dwindling water resources; developing and growing drought-tolerant crops; protecting the biodiversity which will be required for providing livelihood options in the future, etc. Much more requires to be done in this area to ensure global food, nutrition, and income security (and thus contribute to meeting SDGs). And this needs robust and strengthened international cooperation, along with enhanced funding from different sources.

B. Land, Soil, and Water Management (LSWM):
Agronomic research and development for improving the natural resources base (such as land, soil, and water) to aid agricultural productivity are mostly site-specific. The tangible products of such research cannot be directly transferred on a wide scale; they need to be fine-tuned to suit local conditions. Therefore, multilateral international research on LSWM has been mostly strategic and adaptive, focused primarily on developing concepts and principles, as well as processes and research methodologies, to improve the physical resource base. Numerous examples of such strategic research are available with CGIAR Centres. Examples include systems and process-oriented research at the watershed scale, understanding the links and interactions between land and water management practices and the agroecology (soil productivity, structure, chemistry, biology, etc.), and understanding the process of land degradation, etc., all of which are activities that contribute directly to SDG 15 (sustainable use of terrestrial ecosystems) and indirectly to other SDGs.

***Watershed management**:* Watershed management research focused initially on developing concepts, methods, and options for managing the underutilized black soils in India. Along with the Indian Council of Agricultural Research (ICAR) and other partners in the national agricultural research system (NARS), ICRISAT demonstrated the value of treating the watershed as a base for research on soil and water management, hydrology, improved cropping systems, and for monitoring productivity and sustainability on an operational scale (Shiferaw et al 2004). Based on the results of such watershed-based studies conducted in different agroecosystems of India, large-scale watershed management projects were launched throughout the country. A full-fledged rainfed farming division was created under the Ministry of Agriculture at the national and state levels, to oversee watershed-based integrated rural development for food security, environmental protection, and poverty alleviation. With its experience in India, ICRISAT extended the watershed management approach to other countries, such as Thailand, Vietnam, and China. The watershed-based black soil (vertisol) management technology was also extended to Ethiopia, in cooperation with Ethiopian NARS, the International Livestock Research Institute (ILRI), and the Government of the Netherlands.

ICRISAT and its NARS partners have developed an innovative farmer-participatory integrated watershed model (Wani et al. 2002), which has been recognized as an important institutional innovation. The watersheds are now increasingly being used as platforms for launching developmental activities that provide not only land and water management solutions, the benefits of which may take some time to become evident, but also as a basis for broader livelihood programmes, adopted by several development investors, such as the World Bank

Soil Productivity: International cooperation also played a major role in developing new technology to improve soil productivity. Strategic studies on soil management have led to the development of methods, tools, principles, concepts, and processes that are expected to be used by partner countries to develop location-specific technologies to improve soil productivity and enhance sustainability. Some examples are (1) micro-dosing for resource-use efficiency in the West African Sahel; (2) "tied ridges" technology for moisture conservation and crop use in Asia and the Sudanian zone of West Africa; (3) traditional water harvesting systems in the arid and highlands regions of West Asia and North Africa; and (4) diversified fertility management systems in Asia and Sub-Saharan Africa.

There are many other soil management technologies which were originally developed in one country and transferred to many other countries. For example, an animal-drawn tool carrier (Tropicultor) to form broad beds and furrows (for surface drainage) in vertisols in India was adapted in Ethiopia, where the oxen-drawn local plough was modified to suit local needs. The tool carrier concept was further modified and adapted for West African conditions, and a donkey-drawn cultivator-cum-seeder is being used in Mali, Burkina Faso, Senegal, and Niger.

Alliances: In addition to multilateral cooperation for strategic and applied research on land and water management through institutions like IARCs, several bilateral and regional cooperative activities have been operational around the world, through partnerships and alliances. For example, the International Rainwater Harvesting Alliance (IRHA), a Swiss-based alliance, focuses on promoting rainwater harvesting as an effective and sustainable solution in the face of water shortages (https://www.irha-h2o.org/en). IRHA implements projects on land degradation, integrated water management, and agroforestry in partner countries. It also hosts workshops, webinars, and training courses on rainwater harvesting, in cooperation with partners. Similarly, countries in the Eastern and Central Africa together established a regional network on soil and water management research (SWMnet) to coordinate and share soil and water management technology in the region. SWMnet also played a major role in strengthening the capability of NARS in conducting soil and water management research, and in sharing successful soil and water management technologies across the region, thus enhancing the impact of research. The USAID-supported collaborative programme on Soils (TROPSOIL CRSP) is another example of international partnerships in soil management research and development between the U.S universities and host country institutions.

C. Plant Genetic Resources

Plant genetic resource (PGR) or plant germplasm is the foundation of crop improvement and crop diversification; it provides the basis for food and nutrition security, as well as for sustainable agriculture and environment, both locally and globally. PGR includes landraces developed by farmers and modern cultivars and advanced lines developed by plant breeders, crop wild relatives (CWR), and other wild plant species. Globally, about 7.5 million germplasm accessions of different crops are conserved *ex situ* in >1750 gene banks; about 11% of those are in 11 IARCs, and the rest in national and regional genebanks. While PGR is at least as important as the other biological resources of each country, not all countries are equally endowed in this respect. Hence, international cooperation is essential for the effective conservation, exchange, and utilization of PGR.

There are numerous examples of cooperation in the conservation of PGR, including collecting and exchange of PGR, repatriation (when a country loses some of its PGR), evaluation and screening, information and data management, the supply of germplasm seed/propagules, the enhancing capability of countries, and sharing of benefits with the providers of genetic resources. In addition to the efforts of national governments, such collaborative activities have been funded mostly by international donors (e.g., World Bank, Global Environment Facility, Asian Development Bank), aid agencies of countries (e.g., USAID of US, GTZ of Germany, ACAIR of Australia, JICA of Japan) and philanthropic organizations (e.g., Ford, Rockefeller, and Bill & Melinda Gates Foundations). Those collaborative efforts have led to the development of technologies that help us to better understand genetic and species diversity and reduce genetic erosion; they have accelerated the use of genetic material, thus contributing to sustainable development.

International cooperation in PGR, via the exchange of useful plants between and among the countries, has existed over the millennia, even when the concept of PGR did not exist. As humans settled down and started agriculture, informal exchanges of seed have happened through the movement of people. Later, explorers, traders, and botanists contributed to such movement of seed across countries and continents freely. However, purposeful PGR collection and conservation efforts started only in the second half of the 20th century. Initially, PGR was collected within a country; through bilateral collaboration, followed by multilateral support of FAO and CGIAR centres in the late 1960s and 1970s. The International Board for Plant Genetic Resources (IBPGR, presently Diversity International), supported by FAO and CGIAR, assisted researchers from different countries in collecting germplasm in 136 countries between 1975 and 1995; about 200,000 samples of a wide range of taxa and were collected and distributed to genebanks around the world for conservation and use. This was the basis for the present food security in the world (Pierce et al. 2020). The CGIAR centres have collaborated in developing the different protocols needed for *ex situ* conservation (e.g., *in vitro* conservation, cryopreservation, etc.) and in evolving concepts and strategies for *in situ* conservation. Even when severe restrictions on the movement of seed exist, as at present, the Svalbard Global Seed Vault is a clear example of international collaboration in *ex situ* conservation of PGR (see https://www.croptrust.org/our-work/svalbard-global-seed-vault/).

More recently, the Global Environment Facility (GEF) has funded, through the United Nations Environment Programme (UNEP), projects which were implemented by some developing countries, including India, under which collecting activities were undertaken. These projects were implemented under the stewardship of Bioversity International (for example, Conservation and Sustainable Use of Wild and Cultivated Tropical Fruit Tree Diversity for Promoting Livelihoods, Food Security and Ecosystem Services).

The exchange of germplasm among countries has become routine in modern agriculture. For example, several IARCs have been involved in distributing breeding nurseries and advanced breeding lines (as we describe later) to collaborating countries, which often included some germplasm accessions. With the advent of CBD, PGR lost its ‘common heritage’ status because CBD recognised sovereign rights of a country on its biodiversity. This was followed by the development and ratification of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) by FAO. As a result, the collection and germplasm exchange activities virtually stopped, except for the exchange facilitated by the CGIAR genebanks and a few bilateral exchanges.

As many countries are dependent on international cooperation in exchange of germplasm, agricultural scientists are now concerned about this rapidly changing situation, leading to an uncertain future. Hence, it is imperative to recognise that PGR is an integral part of global biodiversity, and that conservation and use of it through international cooperation is a common responsibility of us all. The funding situation needs to be redressed, to make a much-needed comeback in international cooperation for the conservation and use of PGR that directly contributes to UN SDG 2 (zero hunger), SDG 15 (life on land), and SDG 17 (partnership for global development), as well as several other SDGs.

D. Crop Improvement

Crop improvement (CI) involves altering plant traits that are desired by farmers and consumers through introducing new variation, unlocking the variation through hybridization, or creating new material through mutagenesis, and then selecting for the most desired genotypes. More recently, various biotechnologies have been employed to speed up the process, by introducing genes from unrelated taxa or by editing genes. Thus, CI uses a basket of technologies to meet its objective(s). Although in principle, CI is as old as agriculture itself, it is only with the advent of genetics that it has become a more science-based practice. While many countries have had formal CI for the past few centuries, the exchange of germplasm and improved plant genetic material has occurred only more recently, mainly on account of extensive international cooperation, resulting in notable global food production increases. Many developing countries have been able to meet the food demands of their ever-increasing population and thus avoid a global food crisis, as a result of such cooperation. The ‘Green Revolution’ would not have been possible without the widespread international exchange of advanced breeding lines and finished varieties, which were freely made available to many developing countries as Global Public Goods (GPGs) from the IARCs.

The formation of IARCs, initially supported by the Rockefeller (RF) and Ford Foundations (FF), was itself the result of the global food crisis in the 1950s and 1960s. The first two IARCs had a clear mandate to exchange elite breeding materials and knowledge for CI research among the NARS. The International Rice Research Institute (IRRI) was established in 1960 in the Philippines (with funding from RF and FF), while CIMMYT (International Maize and Wheat Improvement Center) was established in 1966 in Mexico by transforming the erstwhile Inter-American Food Crop Improvement Program.

After genetic resources, crop improvement has possibly been next in delivering tangible benefits through international collaboration. The development of a variety from germplasm to the stage of release for large-scale cultivation can take several years, especially if the programme includes CWR and is a joint venture between many partners. International collaboration in CI could involve one or more of the following activities:

- Sharing of early and/or advanced generation breeding lines as Screening Nurseries
- International Disease and Pest Nurseries
- Collaborative Farmer Participatory breeding (projects by a few IARCs)

There are several examples of significant and positive impacts of international collaboration on crop productivity and production in many developing countries. The shining example is the 'Green Revolution' in India, Pakistan, and other countries in South and Southeast Asia. The green revolution avoided hunger and malnutrition in many of these countries by increasing both yield per hectare and total production of staple cereals—rice and wheat. Heisey et al. (2002) reported that wheat breeding at CIMMYT from 1966 to 1997 resulted in an average annual increase in yield of 0.4 t/ha, and >80% area planted to high-yielding varieties (HYVs) in developing countries (62% were CIMMYT-derived varieties, and another 20% varieties involved CIMMYT crosses). They also estimated that the number of varieties released in developing countries would have been 32 to 45% less in the absence of international collaboration. For a total investment of US$ 100-150 million per year, international collaboration in wheat improvement produced annual benefits of > US$ 1.6 billion, as per their estimates; also, in the absence of international wheat research, real prices of wheat would have been 26-34% higher, and area planted to wheat would have been 3-4% higher.

Another example is the impact of ICRISAT chickpea breeding in the central dry zone of Myanmar. When improved short-duration varieties of chickpea (Yezin 3, 4, 5, and 6, derived from ICRISAT breeding lines) were released in the early 1990s, it captured the attention of farmers as the new varieties matured in 75-80 days (compared with 95-100 days of farmers' varieties) and gave higher yields. By the year 2000, the adoption of improved short-duration chickpea varieties was more than 60%. The adoption of Yezin 3 (ICCV 2) increased the chickpea production to such an extent that the government allowed export of chickpea, which was hitherto banned for more than three decades.

An efficient and sustainable international collaboration needs many willing partners/institutions, with clear goals and the ability to carry out efficient research within available resources. Collaboration among institutions producing international public goods (IPG) has been the key to the smooth functioning of the system. Many NARS tend to depend on IARCs for pre-bred lines, early generation populations, and advanced generation breeding lines, as they may not have the expertise (e.g., making wide crosses and crosses involving CWR or biotechnology tools) or the resources to invest in such research. Many NARS, including the relatively strong ones like China and India, have benefitted greatly and released many improved varieties. The IARC system is a good example of an open-source approach for producing IPGs. This approach holds promise even today when the exchange of plant material has become difficult due to the emergence of new regimes, such as Intellectual Property Rights (IPRs), CBD, and other international treaties.

International collaboration in CI has thus been beneficial to many countries, and the funding that has gone into promoting such collaboration is considered well-spent. However, such collaborative programmes are on the decline. There is a strong need to support, strengthen, and reinforce international collaboration in CI in IARCs and other regional or multilateral agencies to ensure food and nutrition security in many developing countries, especially those which are less endowed with expertise and/or resources. Considering that many poor countries will also soon be adversely affected by the negative effects of a changing climate on agriculture, to add to their exiting woes, increased international collaboration is imperative.

The declining trend in funding for ARD must be reversed to allow IARCs and other related organizations to strengthen crop improvement research, using new genomic tools and techniques, and to provide both early and advanced generation breeding materials to NARS in developing countries. At the same time, national breeding programmes should also be strengthened, and the exchange of breeding materials encouraged among the developing countries, aided by bilateral or multilateral cooperation. As noted by FAO recently, the world might fall short of its target of reducing hunger (SDG 2, zero hunger) and SDG 17 (partnership for global development) without such reinvention of international funding for cooperation in CI.

E. Improving Seed Systems

Good seed is the foundation for agriculture everywhere, and for maintaining agrobiodiversity on farms. Farmers' access to quality seed of traditional or improved varieties is vital to increasing crop productivity and food production. Therefore, it is essential to have successful seed systems, with the ability to produce adequate quantities of quality seed, backed up by appropriate research on seed technology, as well as adequate storage and distribution facilities. Even where the seed system is very basic, nodal farmers should be encouraged to pay more attention to seed quality, and informal networks can also play that role.

There are three major types of seed systems (SS): (i) Formal SS; (ii) Informal SS; and (iii) Integrated SS, each playing an important role. Formal SSs refer to systems that are operated by governments or government-supported agencies and/or private seed companies, mainly to deliver improved crop cultivars to farmers. Informal SS, which include farmers' self-saved seed, informal seed markets, and community or village-level seed systems, are the primary seed source of most food crops; they are critical to producing a diversity of food crops to ensure livelihood and dietary diversity in smallholder farming communities. Integrated SSs, which use the strengths of both the formal and informal SSs, have been devised and used by IARCs—through international cooperation—to improve seed production and delivery systems, and to ensure that the improved varieties thus developed reach the smallholder farmer. Integrated SS focus mainly on the seed of improved varieties, developed through farmer-participatory varietal selection projects, and then multiplied and accessed through partnerships.

Seed value chains involve breeders, seed producers, seed processors, seed certification agencies, private seed companies, seed traders, and the farmers. Strengthening the capability of all actors in the chain is critical for sustaining the seed systems. In many cases, funding is critical for developing and strengthening a seed system. Development of a formal or integrated SS in a country is a necessary support for plant breeding research, so that genetic improvements are delivered to farmers, while an informal SS develops based on a community's need and effective interpersonal relations and communication. Even at the informal level, seed traders may benefit from some professionalism (Sperling et al. 2020).

Realizing the importance of seed systems, donors had supported bilateral and multilateral collaboration for developing viable seed systems in individual countries and regions. In the 1970s, many developing countries were ill-equipped to supply high-quality seeds of improved varieties to farmers, and international cooperation played a major role in establishing strong seed systems in some of those countries. The National Seed Projects (NSPs) supported by the World Bank helped countries (such as Bangladesh, China, India, Indonesia, and Pakistan) to enhance infrastructure and train staff to produce, process, pack, and supply quality seeds to farmers.

Some countries, which have unique and successful seed production and distribution systems, shared their experiences and expertise with other countries to help them overcome the bottlenecks in seed supply. Some examples:

- The Pan African Bean Research Alliance (PABRA) has supported participatory breeding and varietal selection, and organized seed fairs, supplying small seed packets that poor farmers could afford to buy.
- The West African Seed Alliance (WASA) has involved multilateral partners including NARS, IARCs, seed companies, seed producers, agro-dealers, and donors, for harmonizing seed policies and partnering with private sector companies from India, Europe, and the USA.
- The partnership between India's Central Potato Research Institute (CPRI) and the International Potato Center (CIP) has enhanced the availability of seed potatoes in West Bengal (India).
- Bioversity International, Nepal Agricultural Research Council (NARC), and a local NGO are working together to strengthen smallholder seed enterprises (SSEs).

Both bilateral and multilateral collaboration are crucial in improving the seed systems in developing countries. But such collaboration can succeed only with committed stewardship, possibly through regional partnerships and networks (coordinated by the national programmes or an IARC), and with one or more donors who are neutral facilitators. Experiences in establishing a strong seed industry in India, for example, can be very relevant to developing countries in Africa and elsewhere. Private seed companies from Asia, Europe, and the US have also a major role to play in strengthening seed systems in countries that need it. By developing robust seed systems for technology transfer from researchers to farmers, especially smallholder farmers, the foundation can be laid for future global food security and seed trade (UN SDG 2, zero hunger, and SDG 17, partnership for global development).

F. Integrated Farming Systems

An integrated farming system (IFS) is defined as an agricultural system which combines the activities of crop production (including horticultural crops), animal husbandry, fishery, forestry, and allied activities within a given target area. It is an efficient, sustainable production system, which promotes higher income and minimizes risk, using mostly local resources. International cooperation in IFS research has been multidisciplinary, and it has focused on developing a scientific basis to systems improvement, by contributing to (or enhancing) our understanding of the ecophysiology and agronomy of major production systems. All relevant components are considered (including crops, animals, trees, and the physical resource base), and appropriate recommendations developed for specific agroclimatic zones and production systems. IFS is thus a collective term for varied kinds of land use (forestry, agriculture, and/or animal husbandry) practiced around the world.

The IARCs have been researching on improving the components of IFS in their respective mandate areas, focusing mostly on cropping systems, crop management strategies, crop and livestock systems, and agroforestry. Natural resources management (NRM), risk aversion, and diversification have been the key principles followed in developing sustainable IFS (including integrated nutrient and pest management strategies) in different agroecologies.

Some examples of effective international cooperative research on integrated/holistic farming systems are as follows:

- A package of technologies for year-round double-cropping by managing the deep, heavy black soils (vertisols) of Asia and Africa, which are traditionally left fallow during the rainy season and cropped only in the postrainy season on stored soil moisture, has been adopted by farmers.
- The African Market Garden, a 500 m² drip-irrigated vegetable system, which integrates high-value vegetable crops in cereal-based systems to enhance farmers' income in the semi-arid dry tropics of West Africa, has been designed and developed, enhancing the productivity of the traditional mixed farming system.
- Biotic and abiotic factors, which affect productivity and the conservation of natural resources, have been quantified in targeted production systems.
- Socially, economically, and technically acceptable strategies have been developed to conserve land and water, and to maintain soil productivity.
- Improved understanding of the process of land/soil degradation has been gained in various target production systems.
- Sustainability indicators, which can predict long-term gains or losses for a given technology, have been identified.

International cooperative research on IFS has also yielded other, knowledge-enhancing outcomes, which include the following:

- generation and dissemination of new knowledge through publications, conferences, and workshops;
- improved ability of NARS in systems research through training and networking and conducting adaptive farmer participatory research in different agroclimatic regions; and
- dissemination of the principles and methodologies for designing sustainable NRM options for the targeted areas.

Those outcomes have generated multiplier effects that stimulate productivity and environmental benefits from the adoption of improved cropping and farming systems in different agroclimatic regions and production systems (Willey, 1988). The scientific principles and concepts developed through international cooperation have been utilized by several NARS to develop technologies needed for their specific needs. For example, scientific knowledge of mixed cropping generated in Nigeria and Uganda has been used to develop methods to improve intercropping systems in India. These systems were further tested and adapted to Niger and Mali conditions (Shifferaw et al. 2004).

International cooperation has enabled agroclimatologists to characterize various production systems precisely, providing a sound basis for the design and transfer of agricultural technologies and the exchange of technologies across countries and regions. For example, several component technologies developed in the arid areas of Thar desert margins (Rajasthan, India) were found applicable in the Sahel and desert margins of West Africa. Similarly, germplasm collected in the West African Sahel region provided a good source of downy mildew disease resistance to Asian pearl millet varieties (Shiferaw et al. 2004).

Simulation modelling of production systems has been another major activity of international agricultural research. Research coordinated by the IARCs has played a pivotal role in developing and adapting various models, which have assisted in identifying the best management practices and in the upscaling and dissemination of new approaches and technologies. These models not only enhanced the capability of collaborating NARS but also contributed to facilitating spillover impacts of international agricultural research. IARCs and many NARS have been using these simulation models to understand Genotype x Environment x Management interactions, and more recently to examine impacts of climate change on crop yields (Shalander et al. 2019).

The results of research on farming systems and NRM are often not directly transferable across regions and countries. However, the principles, methods, lessons, and experiences of systems research can be adapted to specific biophysical conditions and production systems. Agroclimatic characterization and modelling provide a sound basis for the design and dissemination of improved systems. The global challenges of hunger, poverty, and degrading natural resources require multidisciplinary approaches that tackle them unitedly, calling for cooperation and partnership at all levels. International ARD has played—and should continue to play—a major role in developing model farming systems for further adaptation at local levels.

G. Strengthening NARS

International cooperation to strengthen NARS and their infrastructure has existed since colonial times. The colonial rulers in Asia and Africa utilized their agricultural research and educational institutions for building the capability of their host countries. Such efforts received greater impetus in the second half of the 20th century, with young professionals from Asia and Africa receiving higher education/training in agriculture and allied areas in USA, some European countries, and more recently in Japan and Australia. The success of such bilateral cooperation is widely known and recognized by both the host and the donor countries. For example, the USAID played a major role in establishing a strong agricultural institutional base in India, by assisting in the establishment of many state agricultural universities, which later became strong hubs for agricultural research, extension, and education. Besides, bilateral cooperation by philanthropic institutions like the Rockefeller and Ford Foundations also contributed significantly in institutional development in the developing countries. Bilateral assistance by European partners to Africa resulted in establishing some key agricultural research and educational bases. It must also be noted that several well-trained personnel from developing countries who benefitted from such programmes remained in developed countries and contributed greatly to ARD in those countries; so, this was also mutually beneficial.

Apart from bilateral assistance, multilateral institutions such as CGIAR, FAO, and the Inter-American Institute for Cooperation on Agriculture (IICA), European Forum on Agricultural Research for Development, and other philanthropic organizations, have played important roles in supporting and strengthening NARS in various parts of the world. The ICRISAT-Mali Project is an example of such multilateral cooperation where Mali, ICRISAT, USAID, Syngenta Foundation, and Ford Foundation jointly established a strong West African national research infrastructure for long-term research and development on sorghum and millet-based farming systems in Mali. This

12-year programme was successful in establishing a strong national research base, with the development of a network of regional research stations along with needed laboratory and field facilities, training and technical assistance in crop improvement and resource management research programmes (Shetty et al 1991). This multi-institutional partnership was highly commended as a model of collaboration among international and national agricultural research institutes and donor communities. The availability of a good research infrastructure thus created in Mali through international cooperation provided a suitable base for ICRISAT and other IARCs partners to establish in Mali a regional research hub for the Sudanian zone of West Africa.

Since the establishment of IARCs, the collaboration between IARCs and the NARS has also extended to strengthen research management capability, particularly in the relatively weaker NARS. An example of such a model of cooperation can be found in the ICARDA-Yemen programme, where ICRARDA's technical assistance was sought in preparing a long-term strategy for the development of agriculture in the Republic of Yemen (AREA/ICARDA, 1997).

Several IARCs, along with major donors like the World Bank, USAID, and the European Union (EU), have been successful in supporting the weaker NARS in developing national research strategies and programme implementation plans. For example, in plant genetic resources, some CGIAR centres, led by the Bioversity International and supported by FAO, Japan, and Australia, have assisted several countries to either develop or strengthen national programmes on PGR (the examples in Asia include Bangladesh, China, Fiji, India, Indonesia, Myanmar, Nepal, Papua New Guinea, and Thailand). In several of these countries, where research on PGR did not exist, assistance was provided for carrying it out through the provision of expertise as well as financial support. Assistance was also provided to improve existing programmes or establish new PGR programmes in sub-Saharan Africa.

Networking appears to be the foundation for all activities related to international cooperation. Two examples of successful networks can be readily cited: (1) The Cereals and Legumes Asia Network (CLAN), which has been coordinated by ICRISAT since 1986; and (2) the Pan-African Bean Research Alliance (PABRA), which was originally coordinated by CIAT but is now managed by the national programmes. Other such commodity and natural resource and sustainability monitoring networks in Asia and sub-Saharan Africa have strengthened partnerships among the member countries; they have also enabled sharing of research responsibilities and exchange of germplasm and breeding materials, knowledge, and technologies and resources through partnerships and collaboration. Several PGR networks (both commodity and subregional) for collaboration have also been developed and promoted, the most active one being the International Coconut Genetic Resources Network (COGENT) (https://agritrop.cirad.fr/588984/1/Cogent_bourdeix_2018.pdf). These efforts were supported by donors, such as Japan, ADB, ACIAR, NZAid, and others.

Overall, we have seen increasing South-South cooperation, and also North-South and trilateral collaborations. Such collaboration between North and South have contributed significantly to strengthening NARS in many developing countries. The collaboration between India and some of the African countries (India-Africa partnership) in human resources development is a recent example of South-South and trilateral cooperation. With the support of USAID Feed the Future programme, and India's National Academy of Agricultural Research Management (NAARM), ICAR is actively involved in human resources development of many participating African countries. More recently, Australia and India have agreed to strengthen their collaborative research through a programme called SPARC (Scheme for Promotion of Academic and Research Collaboration).

Networking has thus contributed greatly to strengthening national systems. Networks have the advantage of being supported by one or more premier agency, such as an IARC, and individual countries within the network supporting and strengthening each other, making them one of the most desirable tools for ARD. However, networks need both technical and funding support, without which they cannot be sustained.

3. Looking Ahead

As we have indicated, international cooperation in ARD has a long history, and it was pursued strongly by the United Nations (UN) in the developing world. The seeds for this were sown immediately after World War II, with FAO's efforts to build regional and global research networks for the staple cereals. Until the 1960s the progress was slow, but international cooperation took clearer shape through the CGIAR's network of International Agricultural Research Centres (IARCs), considered as the institutional innovation of the 20th century for foreign assistance to agriculture, which went beyond funding. In their concerted effort to promote international research for agricultural development, the CGIAR and the IARCs have received support from the UN organizations, such as FAO, UNDP, and UNEP; the World Bank and the Regional Development Banks; the overseas aid agencies of several countries; and private philanthropic foundations, such as the Rockefeller, Ford, and more recently the Bill & Melinda Gates Foundations. As we have described briefly in the previous Sections, the knowledge and the products developed by international cooperation have had a significant impact on crop production and productivity, ensuring global food security, reducing hunger, and improving the lot of many communities throughout the developing world.

Funding for international agricultural research saw steady increases until the first decade of the 21st century, with CGIAR spending reaching its peak in 2014. After 2014, however, there has been a general decline of funding support for international ARD (https: asti.cgiar.org/publications). While the reasons for this "donor fatigue" are many, one primary factor is the drop in food prices, mostly because of increased production in many developing countries. This resulted in a shift in donor priorities away from food production, while sectors like health, education, democracy, etc., became their focus. Rapid privatization of research, resulting in patents and intellectual property regimes also contributed to the decline in funding for International cooperation in ARD.

There is general agreement, however, that there are still many global problems to be tackled in ARD, with new challenges to food systems and sustainable agricultural production remaining to be addressed, and that doing so is imperative for the long-term survival of planet earth. Sustainable agriculture requires smart agriculture and the development of integrated systems that address the many dimensions of global agriculture; the enormity of that task requires joint efforts by scientists from different countries and disciplines, so that the global scope is maintained (Dragomir et al. 2019). Thus, there is an urgent need to revive and rejuvenate international cooperation and partnerships in ARD, through multilateral, as well as North-South, South-South, and public-private partnerships.

The factors that affect future food systems would include the following:

- Competition for natural resources (scarcity, overexploitation, and ownership matters)
- Continued hunger, including malnutrition, due to skewed demography and poverty
- More people demanding higher standards of living (mainly in food quantity, quality, and diversity)
- Changes in agricultural productivity and quality, due to climate change
- Systems or patterns of food distribution, marketing, and trade

Critical analyses of the above and other evolving challenges, along with the evolving of new methods or actions that would be needed to address those challenges, as well to make them available where needed, would form the future agenda for International Cooperation. Based on the specific issues already identified in our discussion so far, some priority areas, which would need increased attention in the coming years, are highlighted next.

Revived international cooperation and partnerships to achieve SDGs: Global challenges including poverty, hunger, health, education, economic growth, livelihood security, and environmental needs (including biodiversity, land, and water) call for a well-coordinated international effort, irrespective of developed, less developed, or underdeveloped nations. The present global Covid-19 pandemic underlines the need for enhanced international partnerships to tackle global challenges. But it is also important to look beyond the current disaster and use this as an opportunity to refine and adjust plans. As agriculture and environment cut across most of the SDGs, global cooperation and partnerships remain very crucial to achieve sustainable global development. The emerging vision of agriculture now includes not just producers but also other stakeholders, such as the private sector players who drive the value chain, and the public sector, which helps regulate competition and provides social safety nets. Innovative technologies, developed with the participation of all these stakeholders, locally and globally, are crucial to achieving the desired development goals.

Collecting and analysing global data on the agricultural resource base: International cooperation to collect data that generates the information and knowledge needed for ARD is a key activity, which is now an integral part of almost all disciplines. In global agriculture, information from multiple countries needs to be collected, collated, and interpreted. Such efforts include collection and monitoring of resource base data; location, characterization, and evaluation of data for germplasm accessions; production practices in target commodities; socioeconomic data in various production systems; and factors that affect the physical resource base, such as climate, available land and water, for predicting adaptability of technologies under changing conditions. The analysis of socioeconomic and biophysical data thus collected helps develop a better understanding of the causes, extent, severity, and processes of land degradation, and the complex relationship between natural, human, institutional, and policy factors in target areas. Climatic databases are also needed for developing adaptation strategies to climate variability and climate change; mitigation of the effects of climate change; more active applications of models for phenology and yield forecasting; active promotion of strategic applications, such as response farming at the field level; and for achieving a better understanding of the interactions between physical and biological diversity.

Revitalizing multilateral cooperation for ARD: Enhanced knowledge sharing, innovation, and technology generation, along with widespread diffusion and adoption, all focused on environmentally sound practices, are a pressing need globally. And the need can only be met by the sustained cooperative efforts of many stakeholders (countries, civil society components, regional organizations, and private and public sector organizations) on a multilateral basis. As stated earlier, financial support for multilateral cooperation has drastically reduced during the past two decades, and it has been replaced in part by bilateral cooperation between countries. Although bilateral cooperation is benefiting some developing countries, it has adversely affected multilaterally funded institutes, such as the IARCs. It is hoped that the ongoing reform and restructuring of CGIAR into "one CGIAR" will be able to attract more multilateral support and funding to IARCs to harness innovations that can solve the complex global challenges.

Rejuvenating bilateral cooperation in ARD: Bilateral donor countries have played a major role in institutional development and capacity building for ARD in the developing countries. Such activities are still needed for many countries, particularly in Africa. Unfortunately, the bilateral support for such activities is also declining, because of the changing priorities of donor countries: donor funding is increasingly being diverted from agricultural development to other areas, such as health, education, governance, conflict resolution, etc. But support from bilateral donors continues to be needed for capacity development, as well as for applied and adaptive research to develop much-needed location-specific technologies in developing countries. Bilateral donor support is also needed for facilitating technology exchange among the multilateral IARCs, advanced research institutions, and target countries.

Incorporating emerging technologies and global issues: International cooperation in ARD is particularly needed in the use of new technologies, such as sensors (to sense water, soil moisture, pest prevalence, etc.), automation (of many agricultural activities), engineering (closed systems, synthetic biology, etc.), biotechnology (including gene editing), nanotechnology, and artificial intelligence. The successful development of these technologies and their deployment will need partnerships at all levels to transform agriculture in the developing countries. Such new technologies are widening the existing technology gap between nations, dividing them into haves and have nots in terms of technology. This gap can only be bridged through international cooperation.

The demands placed by the changing climate on agricultural production and productivity will have global repercussions and will require international cooperation to evolve specific solutions. Future research needs to become more dynamic, to deal with such evolving and fast-changing situations. International cooperation can also play a major role in developing equitable and science-based policies on emerging issues, such as global trade and intellectual property rights.

Enhancing public-private partnerships: Historically, public-private partnerships in agricultural technology management have played an important role in meeting food security challenges. Such partnerships are more needed now as the world is undergoing a technological revolution, with new technologies emerging in rapid succession, but without losing focus on sustainability. Besides, private companies involved in seed and pesticide industries have contributed significantly to technology transfer, and such cooperation should be encouraged as complementary to public-funded research. Mechanisms to build public-private alliances that support ARD need particular attention; the social and economic returns from such alliances, which benefit society at large, are significant. Increasingly, private companies are interested in contributing to societal benefits while creating corporate benefits, and this "win-win" motivation could be used to furthering collaboration in ARD. Philanthropic organizations, such as the Rockefeller, Ford, and Bill and Melinda-Gates Foundations, who have played a key role in sustaining the support to multilateral institutions, should also be invited to participate in such alliances.

It is obvious that international cooperation and partnerships in ARD are necessary to achieve global food, nutrition, and income security, as well as the sustainability of natural resources. Bilateral collaboration among nations is needed, but it should not be at the cost of multilateral collaboration. With adequate funding and effective collaboration, the multilateral institutions can focus much better on the perspectives of the less developed nations/regions. The global community would do well to remember the ancient Sanskrit adage, "*Vasudhaiva Kutumbakam*" (the whole world is one family), and aim to harness science and technology in various partnerships, to achieve the global goals for sustainable development. If nothing else does it, the changing climate will make people realize the importance of international cooperation to conserve and protect our mother Earth, where we can all safely live and thrive.

4. References

AREA/ICARDA. 1997. Agricultural Research Strategy. Jointly developed by Agricultural Research and Extension Authority (AREA), Agricultural Sector Management Support Project of World Bank (ASMSP) and International Center for Agricultural Research in the Dry Areas (ICARDA). Ministry of Agriculture and Irrigation, Republic of Yemen, 84 pp.

Dragomir D, M Dragomir, Acs Daniel, and S Popescu. 2019. International cooperation for smart and sustainable agriculture. Pp 326-625 *in* Sustainability Assessment at the 21st century, María José Bastante-Ceca, Jose Luis Fuentes-Bargues, Levente Hufnagel, Florin-Constantin Mihai and Corneliu Iatu (Editors). Intechopen.

Fuglie KO and PW Heisey, 2007. Economic returns to public agricultural research. Economic Brief Number 10. September 2007 United States Department of Agriculture, Economic Research Service. Washington.

Gaffney O and W Steffen. 2017. The Anthropocene equation, The Anthropocene Review, 4: 53-61.

Heisey PW, MA Lantican, and HJ Dubin. 2002. Impacts of International Wheat Breeding Research in Developing Countries, 1966-97. Mexico, D.F.: CIMMYT

Intergovernmental Panel on Climate Change (IPCC). 2013. - Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the IPCC. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

Intergovernmental Panel on Climate Change (IPCC). 2018. Summary for Policymakers. In: Special report: global warming of 1.5°C. IPCC, Geneva, Switzerland.

Pearce TR, A Antonelli, F.Q. Brearley, C. Couch, RC Forzza, SC Gonçalves, S Magassouba, MP Morim, GM Mueller, EN Lughadha, M Obreza, S Sharrock, MSJ Simmonds, BB Tambam, TMA Utteridge, and E Breman 2020. International collaboration between collections-based institutes for halting biodiversity loss and unlocking the useful properties of plants and fungi. Plants, People, Plane 2: 515–534.

Shalander K, S Mamidanna, KPC Rao, P Soumitra, MDM Kadiyala, D Prestwich, and AM Whitbread. 2019. A Multi-Model Systems Approach for Identifying Low Emissions Development Pathways– Analyzing Synergies and Trade-offs in Semiarid Agriculture in India. In: 6th International Symposium for Farming Systems Design, 18- 21 August 2019, Montevideo, Uruguay.

Shetty, SVR, NF Beninati, and SR Beckerman. 1991. Strengthening sorghum and pearl millet research in Mali. Patancheru, India. ICRISAT 84 pp.

Shiferaw B, MCS Bantilan, SC Gupta, and SVR Shetty. 2004. Research spillover benefits and experiences in inter-regional technology transfer: An assessment and synthesis. Patancheru 502324, India: ICRISAT 131pp

Sperling L, P. Gallagher, S. McGuire, J. March, and N. Templer. 2020. Informal seed traders: the backbone of seed business and African smallholder seed supply. Sustainability 12: 7074 (18p); https://www.mdpi.com/2071-1050/12/17/7074

Wani SP, TK Sreedevi, HP Singh, P Pathak, and TJ Rego. 2002. Innovative farmer participatory integrated watershed management model: Adarsha watershed, Kothapalli, India- A Success Story. Patancheru, India: ICRISAT 24 pp

Willey R.W. 1988. Cropping Systems for Drylands. In Challenges in Dryland Agriculture: A Global Perspective. Pp 703-709. Proc. Of the International Conference on Dryland Farming. Aug 1988. Amarillo, Texas. USA