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Dryland Agriculture in Semi-Arid Tropics: Constraints and Opportunities

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William D Dar, PhD, is the Director General of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) located near Hyderabad in Andhra Pradesh, India, since January 2000. Dr Dar has had a long and distinguished career as an educationist, agricultural scientist, administrator, and humanitarian in his native Philippines and abroad in the Asia Pacific region and sub-Saharan Africa. He holds the distinction of being the first Filipino and Asian to be Director General of ICRISAT, a member of the Consortium of CGIAR Centers. He was Chair of the Committee on Science and Technology (CST) of the United Nations Convention to Combat Desertification (UNCCD) from 2007 to 2009. Dr Dar has also been a member of the UN Millennium Task Force on Hunger. Prior to joining ICRISAT, he served as Presidential Adviser for Rural Development, and Secretary of Agriculture in the Philippines (equivalent to Minister of Agriculture), the first ever alumnus of the University of the Philippines Los Baños (UPLB) to become one. Before this, he was Executive Director of the Philippine Council for Agriculture, Forestry, and Natural Resources Research and Development (PCARRD), Director of the Bureau of Agricultural Research (BAR) of the Philippines Department of Agriculture (DA) and Vice President for R&D and Professor of Benguet State University (BSU), Philippines. Dr Dar has received a number of awards and honors, including the Ten Outstanding Young Men (TOYM) of the Philippines, Outstanding Young Scientist of the Year, and Crop Science Society of the Philippines' Achievement Award for Research Management, and Outstanding Science Administrator given by the Philippines Department of Science and Technology. He was also awarded as Distinguished Alumnus of UPLB and Most Outstanding Alumnus of BSU and the Ilocos Sur Polytechnic State College. In November 2002, PCARRD honored him with its highest and most prestigious award, the Symbol of Excellence in R&D Management. In 2003, he was awarded the "For the Sake of Agriculture and Rural Development in Vietnam Award." He was recipient of the 2007 Outstanding Professional of the Year Award in the field of agriculture awarded by the Professional Regulation Commission (PRC) of the Philippine Government. Dr Dar has been the recipient of several honorary doctorates – Doctor of Humanities from Pampanga Agricultural College (PAC) and Doctor of Science (Rural Development) from the University of Southern Mindanao (USM), Philippines (2011); Doctor in International Agricultural Development from Central Mindanao University (2010); Doctor of Technology from Isabela State University (ISU) (2008); Doctor of Resource Management from Benguet State University (2007); and Doctor of Science from Mariano Marcos State University (MMSU), Philippines (2003). In 2009, he was conferred the Father Jose Burgos Award, Ilocos Sur's most prestigious award, for his outstanding achievement in the field of agriculture. In recognition of his excellent and outstanding contribution to pulses research and development, he was honored with the Indian Society of Pulses Research and Development (ISPRD) Lifetime Achievement Award. In October 2009, the University of the Philippines Los Baños (UPLB) honored him with the Outstanding Alumnus Award. In November 2010, he was conferred the Lifetime Achievement Award by the PCARRD Scholars Association, lnc. (PSAl). Dr Dar is a man on a mission and a champion of the poor. He has led ICRISAT into renaissance, excellence and relevance with the motto "Science with a Human Face". His transformational leadership has turned ICRISAT into a forward looking institute, which has been ranked 'Outstanding' consecutively in 2006 and 2007 among the CGIAR centers. His passion is to help alleviate the conditions of the poor people living in the semi-arid tropics of Asia and sub-Saharan Africa.

The drylands or the semi-arid tropics (SAT) cover 6.5 million square kilometers in 55 developing countries and spans 40 per cent of the earth's total land surface (Fig. 1). Home to more than 2 billion people, 1.5 billion of it depends on agriculture for a living, with 600 million comprising the poorest of the poor. About 300 million people in this region live on less than one dollar a day and 700 million on less than two dollars a day, in a constant state of hunger and insecurity. An annual linear rate of population growth of 1.6% for the SAT as a whole implies that there will be about 115 million more mouths to feed between now and 2020 – 46.5 million in Africa's SAT and 69 million in Asia's SAT.

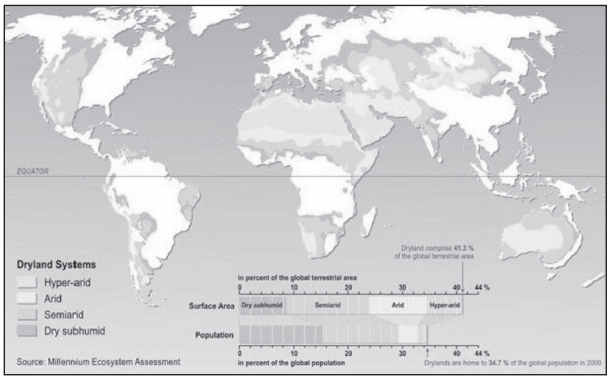

Fig. 1. Map of the dryland systems of the world and corresponding population densities.

Today, the world faces "a perfect storm" of issues that could lead to widespread food shortages and public unrest over the next few decades – climate change, population explosion, energy crisis, food crisis, land degradation, shrinking farm holdings, and loss of biodiversity. The food price hike in 2007-08 and more recently in February 2011 was tragic for many poor people, but it was a good reminder of how increasing agricultural productivity is critical and also how successful agricultural research can impact on poverty favorably by increasing supplies that put downward pressure on food prices for net buyers of food who are the large majority of rural households.

Most of the inhabitants in the SAT struggle to wrest a meagre living from agriculture using subsistence cultivation methods. Tragically, they are missing out on large potential productivity gains that are biologically possible given the soils, crops and climates of these areas, as proven by decades of research across a wide range of dryland locations. Yields could potentially be doubled or even tripled from their current low levels of about 0.5 to 1 metric ton of grain per hectare, particularly through strong positive yield synergies between improved crop varieties, fertilizer and other management techniques (Srinivasarao *et al.,* 2007; Tabo *et al.,* 2007; Twomlow, 2008). On a percentage basis, these potential gains are as large as those achieved in the Green Revolution for rice and wheat. Capturing even a modest portion of them would reduce food insecurity and increase incomes in these impoverished areas.

Apart from bringing new land into agricultural production and increasing cropping intensity and enhancing yields on existing agricultural lands, at least 1.5% of agricultural GDP must be committed to agricultural R&D by developing countries for there to be any signs of impact on the poor and hungry. Mainly, governments and institutions have to take steps towards effective policies and technology investments to minimize food-fuel competition; social protection, especially safety nets, for the most vulnerable groups, including women and children; transparent, fair, and open global trade to enhance the efficiency of global agricultural markets; policies and investments to promote agricultural growth, in particular smallholder productivity; and investments in climate change adaptation and mitigation.

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has an agro-ecological mandate for the semi-arid tropics or tropical drylands of Asia and Sub-Saharan Africa, with primary responsibility for chickpea, pigeonpea, groundnut, sorghum and pearl millet, essential to the diets and livelihoods of the poorest of the poor. The work on these crops is carried out in a systems perspective involving other crops and allied activities. Our mission is to reduce poverty, hunger, malnutrition and environmental degradation in the region, aided by partnership-based international research for development that embodies science with a human face.

Challenges and Opportunities Facing Dryland Agriculture

As growth opportunities in irrigated areas are getting exhausted, the need to improve the productivity of rainfed regions is becoming more compelling on

grounds of equity, efficiency and sustainability. Despite the highly visible agricultural achievements during the last 40 years, dryland agriculture faces persistent challenges which have a bearing on its potential to contribute towards eradicating poverty.

A. Pervasive poverty

The drylands are home to the deepest pockets of poverty on earth, its incidence being higher in rural areas where agriculture is the main occupation. Although the absolute poverty rate in Asia's drylands is less than in sub-Saharan Africa (34% vs 47%), twice as many absolute poor inhabit Asia than in Africa (185 vs 95 million). Using data from the World Bank (2009), Walker (2010) determined that 12 out of 19 of the deepest 'poverty trap' areas in sub-Saharan Africa were in the drylands.

An in-depth analyses carried out under ICRISAT's long-term Village Level Studies over three decades in Africa and Asia show that where poverty is declining, it is largely due to improving connections to urban markets, diversification beyond staple food crops into market-connected activities and off-farm employment.

B. Climate change

It is widely recognized that the increased heat stress, shift in monsoons, and drier soils pose much greater threats to the tropics than the temperate regions. Climate change threatens poverty reduction efforts as the poor depend directly on already fragile ecosystems for their well-being. They lack the resources to adequately defend themselves or to adapt rapidly to changing circumstances, and more importantly, their voices are not sufficiently heard in international discussions, particularly in climate change negotiations. Environmental effects such as desertification and rising sea levels triggered by climate change can lead to increased conflict for resources.

Any recipe for confronting the challenges of climate change must allow for mitigation options and a firm commitment to the adaptation of agriculture, including through conservation and sustainable use of genetic resources for food.

To cope with the impacts of climate change on reduced length of crop growing season, ICRISAT already has on hand crops that are adapted to heat and high soil temperatures, knowledge and understanding of photoperiod-sensitive flowering, information on genetic variation for transpiration efficiency, short-duration varieties that escape terminal drought and high-yielding and disease-resistant varieties. Short-duration chickpea cultivars (super-early ICC 96029, extra-early ICCV 2 and early-maturing JG 11 and KAK 2) that can withstand high temperatures, pearl millet flowering at 40+°C and short-duration groundnut cultivar ICGV 91114 that escapes terminal drought are some examples of our resilient crops for the poor.

ICRISAT's genebank holds more than 119,000 accessions from 144 countries that will help safeguard and exploit genetic diversity in order to enhance adaptation.

C. Nutrition and health threats

Child malnutrition is pervasive throughout the SAT and is a stubborn foe. The consequences consist of greatly impaired national development efforts; reduction in labor productivity, educational attainment in children, school enrolments and attendance; and increase in mortality and morbidity rates and health care costs.

Dryland Asia outstrips Africa in childhood malnutrition (42% vs. 27%) (Walker 2010). Africa's children and the future of the continent are imperilled unless cereal production (Tables 1 and 2) accelerates strongly (Rosegrant *et al.,* 2001).

ICRISAT has made a good beginning in identifying salinity-tolerant and micronutrient dense parental lines in sorghum and pearl millet. This is meant to extend their cultivation to harsh and saline areas and to combat malnutrition (due to micronutrient deficiency), particularly in pregnant women and children.

In addition, HIV/AIDS has exacted an enormous toll on human welfare, particularly in sub-Saharan Africa. One would be hard pressed to design a more pernicious disease, where mortality occurs mainly in prime-age adults aged 20-40 as lifetime income is lost, economic prospects of the current generation of survivors can be

sharply curtailed in caring for the ill and children who could otherwise become orphans, and the children themselves become substantially more vulnerable to the scourge of poverty.

D. Water scarcity

ICRISAT believes that the alleviation of the water crisis in the SAT can happen with the management of "blue water" and "green water". The challenge lies in integrating improved crop varieties, timely planting, fertilization, weed management, conservation agriculture, rainwater harvesting, and supplemental irrigation into smallholder farming systems through an adaptive research and extension process.

Participatory and knowledge-based watershed development programs led by ICRISAT in Andhra Pradesh, Madhya Pradesh, Rajasthan and Gujarat have shown that farmer and public investment can provide attractive social returns leading to poverty reduction. The development of community watersheds in China and India has resulted in increased crop yields (up to four-fold) and increased incomes by 45% and 77%, respectively. Significant evidence of tangible and non-

Table 1. Regional production share and compound annual growth rates in millet (all millets except for India) production, area harvested and productivity

Region/ Country	Production Growth Rate (%)		Area Growth Rate (%)		Yield Growth Rate (%)		Regional Share (%)
	1980-94	1995-2008	1980-94	1995-2008	1980-94	1995-2008	2006-08
World	**0.14**	**1.59**	**0.09**	**-0.23**	**0.04**	**1.80**	**33,513.8** [1]
Africa	3.61	3.17	4.50	0.67	-0.85	2.47	54.5
ESA	0.38	1.56	1.16	0.01	-0.79	1.57	5.3
WCA	4.21	3.44	5.19	1.03	-0.94	2.39	47.0
North America	3.56	3.93	2.58	4.87	0.96	-0.92	0.9
Asia	-1.53	0.06	-2.50	-1.21	0.99	1.27	42.0
Eastern Asia	-5.52	-5.44	-7.00	-5.50	1.61	0.09	5.0
Southern Asia	0.32	1.24	-1.99	-0.81	2.35	2.04	36.0
India [2]	1.50	2.82	-1.06	2.87	2.59	3.12	27.1

[1] Global average production in 1000 t for the years 2006-2008.
[2] Data for India refers to pearl millet data sourced from the Indian Directorate of Economics and Statistics for the years 1980-2008 (2008 figures are provisional estimates).

(Source: FAOSTAT, 2010). The production, area harvested and yield were downloaded from FAOSTAT. Three-year moving averages were calculated for all the data to smooth the seasonal fluctuations. Compound annual growth rates were calculated using the smoothed data series. These growth rates describe the year-to-year growth as if each variable had grown at a steady rate.

Table 2. Regional production share and compound annual growth rates in sorghum production, area harvested and productivity

Region/ Country	Production Growth Rate (%)		Area Growth Rate (%)		Yield Growth Rate (%)		Regional Share (%)
	1980-94	1995-2008	1980-94	1995-2008	1980-94	1995-2008	2006-08
World	**-1.40**	**-0.40**	**-0.67**	**-0.08**	**-0.74**	**-0.29**	**62,218.9** [1]
Africa	2.37	2.68	3.42	1.53	-1.02	1.14	40.9
ESA	-1.62	1.65	-0.80	1.08	-0.79	0.59	7.8
WCA	4.02	3.00	5.28	1.72	-1.24	1.26	24.6
North America	-2.46	-4.74	-3.43	-4.37	1.07	-0.41	17.0
Latin America and the Caribbean	-4.81	1.76	-4.56	0.78	-0.24	1.00	19.3
Asia	-1.16	-3.39	-2.87	-2.66	1.75	-0.73	17.9
Eastern Asia	-2.73	-6.17	-5.99	-7.32	3.46	1.30	4.1
Southern Asia	-0.40	-2.44	-2.49	-2.38	2.10	-0.04	12.4
India (post-rainy season) [2]	0.52	-0.40	-1.33	-1.54	1.82	1.17	12.2
India (rainy season) [2]	0.52	-3.27	-1.33	-3.31	1.82	0.07	

[1] Global average production in 1000 t for the years 2006-2008.
[2] Data for India refers to sorghum data sourced from the Indian Directorate of Economics and Statistics for the years 1980-2008 (2008 figures are provisional estimates).

(Source: FAOSTAT, 2010). The production, area harvested and yield were downloaded from FAOSTAT. Three-year moving averages were calculated for all the data to smooth the seasonal fluctuations. Compound annual growth rates were calculated using the smoothed data series. These growth rates describe the year-to-year growth as if each variable had grown at a steady rate.

tangible benefits has been generated in the form of reduced runoff and soil loss, improved groundwater levels, improved land cover and vegetation, increased productivity and changes in cropping patterns. Income-generating options for the landless and women at Kothapally and other benchmark watersheds have included the setting up of village seed banks through self-help groups, value addition through seed material, product processing such as dhal making, grading and marketability, poultry rearing for egg and meat production and vermicomposting.

E. Land degradation

Land degradation, which manifests variously as escalating soil erosion, declining soil fertility, loss of biodiversity, salinization, soil compaction, agrochemical pollution, desertification and water scarcity and nutrient depletion, often results in loss of soil biota, plant and animal species, and concomitant risks to the sustainable production of food and ecological goods and services. ICRISAT addresses the problem of land degradation by undertaking sustainable land management strategies such as integration of crops with livestock to generate higher resource use efficiency; diversification of crop and livestock products, with a focus on new fruit trees, dual-purpose legume crops, poultry and small ruminants; raising fertility through microdosing; conservation agriculture; and integration of woody plant management with crop and livestock activities.

Strategic Science

New scientific tools are increasingly being used to enhance the precision and pace of genetic enhancement of dryland crops. ICRISAT is harnessing biotechnology to develop new varieties that are drought tolerant. Molecular markers associated with shoot fly and stem borer resistance, tolerance to terminal drought in sorghum, resistance to downy mildew and tolerance to drought in pearl millet are being developed. The success of our marker-assisted selection led to the development of the downy mildew-resistant HHB 67 improved in collaboration with the Haryana Agricultural University (HAU) of India, enabling farmers in Haryana to save $6.7 million during the first year of adoption through reduced disease levels. Among other achievements are the extra-short duration (ICCV 2) and short-duration (KK 2 and JG 11) chickpea varieties and pigeonpea hybrid ICPH 2671 that escape terminal drought. ICRISAT is also harnessing biotechnology to develop new varieties that are drought tolerant.

Among the broad range of innovations that have made a significant difference in improving agriculture and the livelihoods of the poor, include early-maturing fusarium wilt-resistant varieties of both *desi* and *kabuli* chickpea. Between 1973-74 and 2008-09, they led to an 11-fold increase (974%) in area, a 45-fold increase (4387%) in production and a 4-fold increase (318%) in productivity of the crop in Andhra Pradesh.

Similarly, our extra short-duration pigeonpea cultivar ICPL 88039 that matures 10-12 days earlier than the local cultivar was found best suited for rotation with wheat in the Northwestern plains of India.

Diversification

The objective of diversification is to encourage farmers to grow a mix of diverse crops in order to reduce various types of risks. Growing fruit and vegetables allows poor farmers the opportunity to derive additional income and increase enterprise stability in the face of natural shocks as well as improve diets. It also enables them to move away from reliance on staple cereals, pulses and starch crops and through diversification of their cropping systems into high value commodities so that they can make the transition from subsistence to market-oriented agriculture.

While the focus of ICRISAT's research in East and Southern Africa is on linking farmers to markets and diversification into higher value legumes, in West and Central Africa the spotlight is on integrating trees and vegetables into cereal systems. In Asia, its community watersheds program has introduced fruits, vegetables, herbs and medicinal plants to improve livelihoods, nutrition and health. Among its mandate crops, fresh green chickpea pods are an important source of income when vegetables are scarce in Ethiopia. In Kenya, Tanzania, Malawi and Mozambique, ICRISAT's early-maturing pigeonpeas capture off-season high prices for green peas consumed as a vegetable.

ICRISAT has also supported the setting up of 2500 African Market Gardens (AMGs) in West Africa, a concept that combines low pressure drip irrigation systems with high-value crop diversification to enable the commercial integration of fruit, vegetables and trees in the dry Sahel. These "market gardens" can be tended by women's groups to both increase their incomes and diversify their family's diet, multiplying their incomes by several-fold, in some cases more than 10-fold to US$ 1,500 from an area of only 500 square meters.

ICRISAT in collaboration with ILRI animal nutritionists has improved the digestibility of crop residues of mandate crops that have a significant impact on milk production, particularly in South Asia. Haulm of groundnut variety ICGV 91114 introduced in Anantapur district of Andhra Pradesh led to a 20% increase in milk yield of diary animals of farmers adopting the improved variety.

Institutional Innovations: Partnerships Hold the Key

Given these daunting challenges and constraints in the SAT, achieving food security represents an opportunity for which no single institution can hold all the expertise needed. To succeed we need partnerships that address all the weak points in the system. The strategic partnerships established by ICRISAT with stakeholders from both the public and private sectors are effectively addressing complex developmental issues in agriculture. In 2010, we were involved in 190 active partnerships and distributed 20% of our budget to partners to execute joint research-for-development activities.

Consistent with the innovations paradigm, ICRISAT's portfolio has come to include activities that support private-sector incubation and capacity strengthening, funding from charitable foundations associated with the private sector, and wide-ranging programs to commercialize its technologies through the private sector. Our Agribusiness and Innovation Platform (AIP) comprising the Innovation & Partnership (IP) Program, the Agri-Business Incubator (ABI) Program, and the NutriPlus Knowledge Program are among some examples of successful and innovative partnerships. AIP has stimulated over 100 joint ventures with agri-business entrepreneurs in India over the past five years.

Reorienting Policy

Dryland farmers have been driven to cropping patterns favoring cash crops (like cotton, soybean, castor and sunflower) or high value agricultural products that have a market demand but are not best suited to the prevalent soil and water moisture regimes.

Dryland agriculture can emerge as a market-oriented, commercially viable, and ecologically sustainable means of producing food, fibre and raw materials to benefit the small farmer through a multi-pronged strategy that involves reorienting policies (rationalizing subsidies on agricultural inputs and covering more crops under the minimum support price); higher public investment in technology, infrastructure, and markets; addressing chronic trade deficits in pulses and oilseeds; integration of labour markets; institutional innovations, partnerships and capacity building; higher inflow of institutional credit to dryland agriculture, coping with the challenges of globalization, and facilitating migration.

Inclusive Market-Oriented Development (IMOD) : The New Way Forward

Dryland poverty rates are declining in Asia, but not in sub-Saharan Africa. Analyses by the World Bank and ICRISAT have found that access to markets is key to escaping poverty. Gleaned from its rich knowledge base spanning 38 years in partnership with institutions, strategic studies, long-term village-level studies, as well as global studies by the World Bank, the Institute has adopted Inclusive Market-Oriented Development (IMOD) as a guiding framework of its new Strategic Plan to 2020 to empower smallholder farmers to grow their way out of poverty (ICRISAT, 2010). IMOD is a dynamic progression from subsistence towards market-oriented agriculture which will achieve a new level of access to resources, stability and productivity for poor smallholder farmers (Fig. 2).

ICRISAT's new strategy to 2020 is about harnessing markets to achieve its four Mission goals to elevate the poor out of poverty, hunger, malnutrition and environmental degradation across the dry tropics of the developing world, aided by purposeful partnerships. It includes a systems perspective that looks at how innovations fit together to make a functioning whole

that helps the poor move steadily along a path from subsistence farming to market-oriented farming.

IMOD pays greater attention to women, whose children are the dryland's future and who risk being left behind by markets. It is also about building resilience, the ability to withstand and recover from stress, which in the drylands, includes human, social, physical, natural and financial stresses. We believe this is the way we can meet our aspirational targets of halving the incidence of poverty in smallholder farming households; halving the incidence of hunger, halving childhood malnutrition and significantly increasing the resilience of tropical dryland smallholder farming.

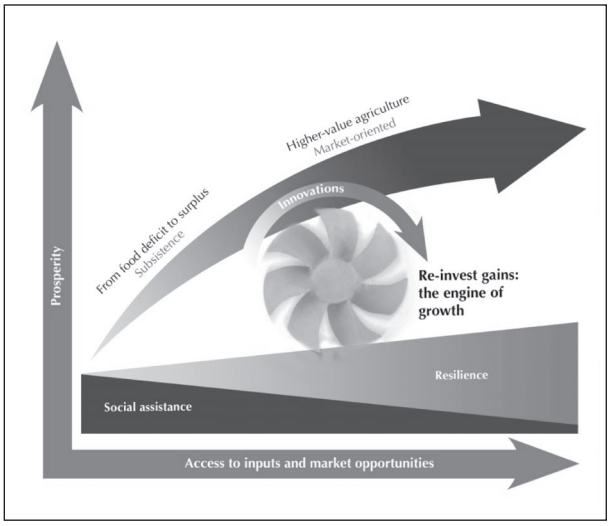

Fig. 2. Map of the dryland systems of the world and corresponding population densities.

Conclusion

A broad vision for dryland agriculture would involve reducing poverty, hunger, and malnutrition, and ensuring sustainable livelihoods for everyone. This vision can be achieved through a multi-pronged strategy to accelerate the pace of development of dryland agriculture, which requires synergies among innovative policies, appropriate institutional arrangements, market-driven technologies, input supplies and credit to benefit the dryland poor farmer. Greater emphasis on the seed sector, input use efficiency, financial and insurance institutions and a paradigm shift in technology transfer mechanisms can bring the dryland poor closer to food security.

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