RAINFED AGRICULTURE: RESOURCE BASE, TECHNOLOGIES AND SOCIETAL IMPERATIVES*

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Abstract

Globally, rainfed agriculture covers about 40 percent of the world's land area spreading across 55 countries where more than 2.5 billion people live and depend on agriculture for their livelihoods. In India, about 70% cultivated land supporting about 40 percent of India's population and contributing to about 45% of the India's food basket is rainfed. Unlike irrigated areas, where green revolution ushered significant gains in agricultural productivity, rainfed regions continue to suffer from low productivity (< 1ton/ha) due to uncertain rainfall, frequent droughts, degraded land and other fragile natural resource base. People living in these areas are poorest of poor where large proportion of children – about 42% are malnourished. Increasing climate change and climate variability pose new problems in the form of changes in rain fall and temperature patterns coupled with more extreme weather events.

In India, significant advances have been made by various research and development organizations including state agricultural universities, national (CRIDA) and international (ICRISAT) research and development programs to improve rainfed agricultural productivity and conservation of natural resources. Adoption of various improved technology options resulting in increased yield potential of up to 250-300% on large pilot/operational scale areas has been recorded. This paper highlights examples of some component technologies including improved soil and crop management, rain water harvesting and use through watershed management, ground water recharge, soil health and integrated nutrient management, crop diversification and cropping systems, alternative land use systems, farm mechanization, agro-forestry and integrated farming systems.

As rainfed agriculture is mainly practiced under fragile resource base, special emphasis is placed on achieving optimum complementarity between natural resources conservation and productivity. The paper highlights technological options for increasing productivity and sustainability of physical resources: primarily land and water to maximize the synergies of crop, livestock, tree and forage components of rainfed farming systems. Component technologies for land and water management aiming at optimising land, water and nutrient use efficiency are described. Examples of location specific technologies for rain water management and arresting soil degradation are narrated. Appropriate policies to remove stagnation of rainfed agriculture and manage frequently occurring droughts through substantial capital inputs for building infrastructure and development of land and water to enhance resilience and livelihood security are also indicated.

Evolution of and lessons learned from innovative integrated watershed management approach to raise agricultural productivity, conserve natural resources and reduce poverty in the stressed ecosystems of rainfed areas are highlighted. Individual farmer and community/village-based activities and much needed supporting public policies and institutions are also indicated drawing from recent watershed management projects in India. The importance of effective community participation and appropriate public policy initiatives are elaborated for the successful implementation of watershed management programs. The critical areas effecting the success of watersheds such as adoption of technologies, collective action and participation by communities, cost sharing, distribution of gains (equity) and up-stream and down- stream trade-offs are indicated.

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The paper concludes by recommending a holistic systems perspective to address such critical elements as income generation, diversification and building resilience to enhance sustainability and productivity in rainfed systems. An integrated strategy encompassing modern science, public policy and effective public-private partnerships for sustainable intensification and value-chain development is suggested.

Introduction

The tropical semi-arid regions or dry lands cover about 40% of the world land area spreading over 55 countries with about one third of global population living in these areas. More than one third of these people (about one billion) depend primarily on agriculture. The agriculture here is mainly dependent on rainfall with uncertainty and instability in its precipitation patterns. The mean annual temperature in these areas exceeds 18 degrees centigrade with the rainfall exceeding potential evapo-transpiration for 2 to 7 months. These areas are characterized by fragile resource base coupled with high climatic water demand and by variable and erratic rainfall.

The rainfed farming areas in Asia and Sub-Saharan Africa are the home for about 2 billion people with about 600 million considered to be poorest of poor. Poverty, food insecurity, environmental degradation with frequent droughts is widespread in these areas. About 42 percent of children in rainfed areas of Asia and 30 percent of children in Sub- Saharan Africa are malnourished (Walker, 2010). Rapidly growing population, high urbanization, highest unemployment rate for rural youth and breakdown in social systems further aggravate the challenges facing population dependent on mainly subsistence farming in these areas. Access to water in these areas become even scarcer due to global climate change with more variability and occurrences of short period of extreme stresses (drought and heat) during the crop growing season.

This paper provides an overview of characteristics with special references to resource base and major challenges of rainfed agriculture in India along with presently available technological options to address some of those challenges. The paper also highlights some key elements of alternative approaches for holistic development of rainfed farming areas with a special emphasis on addressing contemporary challenges in natural resources management facing rainfed farming community in India. An alternative strategy to link farmers to markets through market-oriented agriculture development and risk aversion policies with effective public-private partnerships are also described. The paper concludes with suggestions on the way forward to address the sustainable development goals of ending hunger and poverty and sustaining environmental health in the rainfed areas.

Rainfed agriculture in India

In India about 70 percent cultivated lands- contributing 42 percent of the total food production- is rainfed. Rainfed agriculture also accounts for nearly 75 percent of oil seeds, 90 percent of pulses, 70 percent of cotton and supports two-thirds of livestock population. Even after full development of water resources, about 55 percent of the land will continue to be dependent on rains and produce substantial fraction of coarse grains, pulses, oil seeds, cotton, jute etc. The crop production in the rainfed areas in proportion to total production in India is about 30 to 40 percent of wheat and rice, 60 to 70 percent for maize, ragi and cotton, 80 percent of sorghum and millet, 90 percent of oil seeds and pulses, and 100 percent of small millets (CRIDA, 2015). Therefore, the only way to meet the requirements of not only the coarse grains but also to address the shortages of protein, edible oil and cotton is to improve the productivity of these crops in the rainfed areas of the country.

Features of rainfed production systems: Fragile resource base

Rainfed farming areas are characterized by a wide range of climatic, soil, vegetative, and farming conditions and it supports several types of farming systems. These characteristics pose severe constraints to sustainable production within the region.

Rainfall is the principal determinant of the cropping potential. Based on average annual rainfall, the country can be divided into arid (less than 500mm), semi-arid (500 to 750 mm) and sub humid (750 to 1150 mm) area. The rainfed cropping area is equally distributed in these three zones. Nearly, 80 percent of rainfall is received from June to September. The main features of rainfall are:

- Extreme variability of rainfall within seasons and between years with the coefficient of variation increasing with decreasing average rainfall

- The beginning and end points of the rainy season are highly variable leading to unstable production potential

- Rains are generally more intense; a relatively high proportion is lost as run-of

- High temperature leading to high water consumptive demand

- The growing season varies from 60 to 250 days depending upon total rainfall, its distribution, potential evapo- transpiration and soil water storage. Uncertainties associated with rainfall events render farming highly risk prone

The soils are also diverse and varied. Vertisols (black soils) covering about 25 percent area have high clay content with high water holding capacity, but are highly erodible and produce large amounts of runoff. These soils are also low in nitrogen and phosphorous. Alfisols (red soils) cover about 20 percent of area. These soils are low in clay and organic matter content and with poor nutrient status and have low water retention capacity due to shallow depths. They are also prone to erosion and crusting and produce large volumes of runoff. Arid (sandy) soils are found in low rainfall and desert margins. They are characterized by very low clay content, low water retention and poor soil fertility. Prospects of increased crop productivity are relatively low in this region. Sub-montane and alluvial soils are also found in some rainfed areas. These soils are of variable texture, generally deficient in nitrogen and phosphorous and prone to erosion depending upon the topography.

While, low soil moisture availability commonly restricts crop yields, there are several other soil related characteristics which also affect crop production. They include surface soil crusting, compaction by tillage, low fertility and organic matter, restricted rooting depths, poor drainage and salinization. Soil degradation is also a serious problem in the rainfed areas. It is caused by a strong interaction between biophysical and socioeconomic factors, including increased rate of population growth, fragile economies, poorly designed farm policies.(Lal and Stewart, 1992) Soil degradation can be subtle and slow until a certain threshold is reached, where upon degradation occurs quickly and sometimes irreversibly if the spiral of poor land use continues.

The farming systems in rainfed areas are characterized by mixed farming systems where more than one crop is grown on the same piece of land (as sole, inter or sequential cropping), and in combination of trees and animals. These diverse systems provide food security under harsh climatic conditions, but are primarily subsistence or semi-commercial in nature. They are also extensive, based on the low use of commercial inputs and are primarily labour-intensive. The principal crops grown are cereals (sorghum, maize, and millets), pulses (chickpea and pigeonpea) oilseeds and cotton. Majority of the holdings are smaller than 2 ha, and these small holdings are comprised of fragmented parcels.

In summary, the productivity of rainfed agriculture is not only low but also fluctuates from year to year due to poor bio-physical and socio-economic resource base. Besides having erratic rainfall these areas quite often are heavily eroded and have very shallow soils. The rainfed regions are characterized by intense rainfall interspersed with drought, short rainy seasons, low soil organic matter content, poor natural soil productivity, and at times low infiltration capacities of soils, severe runoff and erosion hazard, small and fragmented farms, limited capital resources of the farmers, and animal and human labour as primary draft power sources. In the past, the rainfed farmers had variety of options to stabilize their income from farming such as fallowing parts of the farm to maintain soil productivity, and the availability of common property resources for cattle grazing. Many of those options are no longer available to farmers because of increased population pressure. Also, "green revolution" technologies prevalent in large farm irrigated areas are not directly applicable to the high risk prone small holder rainfed farming situations.

Technological options for productivity and sustainability of agriculture

There exists a large body of research knowledge for sustainable management of rainfed farming. These technological advances are published in a wide variety of books and technical journals. A summary of these technology components is presented below:

<u>Historical research</u>

Efforts to improve the crop production on the dry lands were initiated as early as 1933 by the then Imperial Council of Agricultural research when it sponsored five dry-farming research centres located at Rohtak, Sholapur, Bijapur, Raichur and Hagari (Randhawa and Venkateswaralu, 1979). The recommendations from these centres (known as Bombay, Hyderabad and Madras dry farming practices) emphasized bunding to conserve soil and water, use of manure to supply nutrients, deep ploughing every third year, shallow tillage and inter row cultivation, low seeding and wide row spacing of crops. However, these improved practices resulted in only 15 to 20% increase in yields above the low base yields of 300 to 400 kg/ha which did not enthuse the farmers for adoption. Labour and cash costs and risk involved were too high for the farmers.

In the mid-1950s, a fresh effort was initiated with the establishment of eight soil conservation research, demonstration and training centres. Research emphasis was placed on soil and water conservation to increase and stabilize crop yields through contour and graded bunding, bench terracing and strip cropping. However, the solution to the problem of low crop productivity continued to be elusive as the available crop varieties, being long duration with limited yield potential, did not match the prevailing rainfall pattern and available water supplies in most cases. This and inadequate attention to in situ moisture conservation remained a serious constraint to increasing crop production in rainfed areas.

With the rapid expansion of Indian agricultural research system in the 1960s (through ICAR) plant breeding efforts provided new short duration genotypes of sorghum, pearl millet and cotton which matched the short growing season, thus reducing the risk factor and resulting in higher yield potential. With needed refinement in agronomy, these hybrids/varieties (CSH sorghums, HB pearl millets and FRS cottons) gave large yield increases under rainfed conditions.

Availability of this much needed biological component of short duration, input responsive crop plants provided the breakthrough in crop production in rainfed areas.

Recent research and development efforts

Encouraged by the potential of achieving increased production and recognizing the need for multidisciplinary research approach, an All India Coordinated Research Project for Dry land agriculture (AICRPDA) was formally launched in 1970 at 23 centres spread across the country representing different agro climatic regions. The principal mandate of these centres was to develop relevant location specific technologies to solve production problems. At the same time international interest in rainfed farming also increased, which lead to the establishment of the International Crops Research institute for the Semi-arid tropics (ICRISAT) at Hyderabad. Realizing the enormity and complexity of Indian rainfed agriculture AICRPDA was later strengthened by establishing a national centre (CRIDA) focusing on basic and strategic research to improve rainfed agriculture in 1985. Some of the key research findings and significant achievements emanating from these research efforts are highlighted below (Ref: CRIDA and ICRISAT reports, vision and strategies):

- Resource characterization: From available soil and climatic data, rainfall probabilities including onset and recession of monsoons, dry spells etc have been worked out. Periods of water availability have been identified considering rain fall probabilities, potential evaporation and soil water capacity. Potential length of growing period for all the major production systems in the country is now known so that appropriate cropping systems can be developed for these locations. District level advisory services and contingency plans to cope with droughts were also provided. Mapping areas for rain water harvesting and standardization of farm pond technology was completed.

- Crops and varieties: High yielding, stress tolerant crop varieties were developed to match the growing seasons with limited water availability. For example, ICRISAT has released about 700 improved cultivars along with its partner institutions for use by small farmers in Asia and Africa. These include high yielding hybrids and varieties of cereals, pulses, and oilseeds and the area under these improved varieties have increased rapidly in India. Large number of genetic resources (about 119, 000 by ICRISAT) of the major rainfed crops have been collected, conserved and disseminated.

- Cropping systems: Crop management technologies for various cropping systems including, sole, inter, sequential cropping have been devised to increase productivity of various rainfed agriculture regions. These include dates of planting and harvesting, weeding and inter cultivation and integrated nutrient and pest management technologies.

- In situ moisture conservation: various soil moisture conservation technologies including types of conservation tillage methods, ground cover management, bench terracing, runoff water harvesting in small catchments were devised.

- Soil fertility management: Recommendations on fertilizers, biological nitrogen fixation, and use of organic manures such as animal and municipal waste were developed to manage soil health.

- Improved natural resource management: Techniques to mitigate soil degradation, water and wind erosion management using either preventive measures (such as mulch farming, conservation tillage, vegetative hedges and strip cropping) or through control measures (such as contour bunds or other engineering structures) were evolved.

- Farm tools and implements: To ensure labour and time saving several implements for timely agricultural operations such as planters, intercultural implements, pesticide applicators, portable pump sets for lifting water from farm ponds have been developed.

- Forewarning systems: for weather/drought and pests for different crops/systems developed

- Alternative land use systems: involving crops, agri-sylvi, sylvi-pastoral, agri-horti systems were designed, tested and recommended for various agro-ecological locations.

- Different models: for enhancing livelihood security in rural areas were developed.

<u>Natural resources management through Watershed based research and development:</u>

A significant milestone in rainfed agricultural research was the setting up of watershed based approach to resource conservation and enhancing agricultural productivity. Watershed based approach to dry land resource management was initiated during the 1970s (Kampen et al 1979) with a natural agricultural watershed as a unit for rain water and soil management in dry areas. The approach also provided an opportunity to evaluate the component technologies alone and in combination to document the synergistic effects of resource conservation and crop management technologies on an operational scale (Shetty and Krantz, 1980). Management of large tracts of deep vertisols with watershed-based component technologies was indeed considered as a major success story. During later years a large number of development projects also followed this approach to test and transfer the technologies under farmer/communities' conditions and gained experience of watershed-based development of rainfed agriculture. Watershed management approach has now become a focus and framework for development in the rainfed areas. A brief synthesis of the experience from about three decades of watershed-based research and development is given below:

- Watershed based research and development programme has a long history and has evolved through many years of learning by doing in the rainfed areas with more emphasis on integrating soil and crop management technologies on an operational scale. The three ministries implementing watershed programs: Agriculture, Rural development, and Environment and forests have been investing millions of dollars in rainfed areas mainly to manage natural resource base in dry lands and the programmes have been receiving widespread commitment by the Government and stake holders.

- In the pilot areas the impact of watershed-based management is widely recognized. For example, in the Adarsha/Kothapally watershed in A.P, after four years the average yields of crops increased 2 to 4 times, family incomes doubled, ground water availability enhanced, cropping intensity increased with a shift from low to high value crops, significant reduction in soil loss (10 t/ha to 2 t/ha), reduced run off (30-40%), improved water quality and increased green cover leading to greater carbon sequestration (Wani, et al 2002).

- An analysis of about 310 watersheds by Joshi et al (2004) revealed mean cost-benefit ratio of 2.14, and internal rate of return at 22% which was comparable with many rural development programs. Increased employment opportunities, augmented irrigated area and cropping intensity and conserved soil and water resources were also recorded. The study also concluded that the performance was better in the regions of 700 to 1000 mm rainfall, jointly implemented by state and central governments, targeted to low and medium-income regions, and with effective community participation. The sustainability of these impacts however was not clear.

- While there are visible gains from various watershed development programs, the sustainability of investments made by different agencies has not been ensured mainly because insufficient participation by local communities. The first-generation watershed programmes suffered from a top-down approach and technical focus on only soil and water conservation without sufficient benefits to rural poor.

- With the second generation programmes combining technical strengths of earlier programmes with lessons learnt from community participation the effectiveness of watershed programmes were enhanced. Even after the new policies have been issued, several critical areas continued to affect the success of participatory community watershed management in the country. These are mainly related to profitability of interventions, problems of collective action and active participation by the community, cost sharing by the individual farmers and the community, distribution of the gains (equity) and externalities (upstream and downstream trade-offs). The geographical and social diversity created difficulties in sharing costs and benefits.

- Lack of supportive policies and legislations that encourage cost sharing and private/individual and collective community actions added further complications to watershed programs. The subsidies provided to soil and water conservation investments on private lands made it difficult to assess the real farmer and community demand for the programmes. The sustainability of the benefits from watershed programs (including subsidies) was threatened due to conflicts between private land holders and the community at large (with landless laborers). The conflicting objectives of highly heterogeneous rural social structure made it difficult to implement effective watershed management programs.

- Many case studies showed that the availability of profitable technologies associated with appropriate policies and institutional arrangements and good access to markets encourage people's participation in the watershed programs. Depending on the focus given on technology support, social organization, and market access the experiences indicated that those managed by research organizations and some NGOs were more successful than many government managed watershed programs.

- It has now become clear that watershed based programme has the potential for development of the rainfed areas. Access to technology, markets and equitable access to the conserved water and other economic goods and services determine the success of the program. Equity in sharing the benefits is a vital consideration for effective community (collective) participation.

- The assessment of many case studies (Joshi et al 2004) have clearly shown that more research on technology generation, policy and institutional arrangements are needed to address the many gaps noted in second and third generation watershed management problems and attain the livelihood and environmental objectives in rainfed areas.

Contemporary Challenges:

Rainfed agriculture in India is now in crisis. The problems of farmers have increased due to climate and market risks, increase in cost of inputs, non-availability of labour and rising cost of living. Besides, the aspirations of rural population have gone up creating dissatisfaction among the rural youths towards agriculture resulting in rapid migration to cities. The major challenge to rainfed agriculture will be sustaining the livelihoods of small and marginal farmers who will still depend on agriculture despite shrinking landholdings, manpower shortage and climatic variability. The spiral of poverty is deepening with continuous pressure on land and water resources, and shifting market forces will further aggravate the problem of rainfed agriculture in the years to come. The major challenges which need to be addressed soon are summarized below:

Bridging productivity gaps:

Despite rapid progress in technology generation in the research stations, the farm level yields of crops are still low indicating wide yield gaps due to slow or non-adoption of technologies. A detailed analysis of causes for these gaps and design of location specific technologies with appropriate technology transfer activities are needed to bridge these gaps. Regional imbalances in terms of technology intake capacity of farmers are to be corrected. Selecting productive genotypes with wide adaptability and resilience to variability in climate will continue to be a challenge. Lack of impact of technologies on-farm necessitates a mix of better technology adoption, institutional support and incentive systems to bridge the yield gaps and enhance sustainable production in the rainfed areas.

Managing risks

The greatest challenge to rainfed agriculture will continue to be risk due to erratic monsoon. Climatic risks like drought and floods coupled with edaphic constraints like poor soils with low soil organic matter contents make rainfed agriculture highly risk prone. Though there are solutions to manage this risk (as described earlier), up scaling those evidences into wider adoption continues to be a major challenge.

Risks due to market failures are also serious with small and marginal farmers. Rainfed farmers are poorly connected to markets. Including poor farmers in the value chain development will be a challenge. These farmers require outside help through policy interventions including subsidies, support prices, insurance, emergency food reserves, and other social safety nets. Actions to mitigate both bio-physical and socio-economic risks and assisting small holder farmers to become more and more able to stand on their own and become more resilient should be the major focus in the years to come. For sustainable livelihoods, appropriate technologies (including diversification, genotypes with stable and high yields coupled with tolerance to stresses, location specific soil and water conservation measures, and integrated farming systems etc.) are to be combined with appropriate actions to manage risks. Societal and institutional support to manage the risks of these resource-poor farmers is critical in improving the productivity and sustainability in rainfed areas.

Changing demand profile and nutritional security:

With increasing population and changing food habits in the future the demand for cereals will be low and that for pulses, milk, meat and eggs will be higher. Therefore, rainfed farming needs to adapt to these changes with more focus on livestock, pulses and fodder crops. Also, with the increasing concerns on nutrition and health the demand for nutrition rich dry land cereals/millets will continue to grow. Similarly, there will be increasing demand for fruits and vegetables resulting in more emphasis on dry land horticulture However, since the output of pulses have remained stagnant for a long time the challenge will be to enhance the production of pulses and oil seeds in the years to come. As most of the tribal people and farm laborers in rainfed areas suffer from protein and micronutrient malnutrition the challenge will also be to produce more protein and micronutrient rich cereals and pulses.

Managing water resources:

As the demand for water from non-farm sector increases, the challenge will be to enhance the water productivity (more crops per drop). Also, as noted recently, the conflicts between upstream and downstream water users may increase over time. The fall out may be conversion of presently irrigated lands into rainfed lands and the increase in ground water use. Heavy extraction of ground water will lead to other challenges such as poor water quality and excessive demand for power. Changes in water availability will determine the land use and choice of crops which could form the basis for science-based watershed management programme in the future.

Managing soil health:

As the dry land soils are not only thirsty but also hungry managing soil health will continue to be a major challenge. Ensuring optimum fertility of soils in the backdrop of declining soil organic matter (with declining crop residue recycling) will be a key challenge. Universal deficiency of micronutrients will also be a major issue. With the changing rainfall intensity causing more severe soil erosion, harnessing the synergy between applied nutrients and soil moisture will continue to be a challenge.

Climate change and climate variability:

Studies have already shown that climate change and climate variability impact agriculture in general and rainfed agriculture in particular. Climate models have shown that rainfall is likely to decline from 5 to10% in southern parts of India whereas 10-20% increase is likely in other parts of India (CRIDA, 2015). There is also evidence to show the likely increase in extreme events and likely decline in rainy days. Annual raise in temperature (2 to 2.5 degree C) is also likely, particularly in the northern region. Crop simulation studies have shown the negative impact of future climate (changes in temperature, rainfall and CO_2 levels) on the rainfed crops such as sorghum, groundnut, mustard, maize and wheat. Therefore, weather based risk management in agriculture (development of resilient genotypes and management practices) will be a major challenge. The location specificity of problems, diverse farming systems and insufficient understanding of climate variability therefore calls for concerted efforts by all the stakeholders/institutions to develop climate smart agriculture.

Farm energy security:

Declining availability of animal power, increasing labour costs coupled with rapid migration of rural youth to cities will make small holder agriculture less profitable. Modernizing rainfed agriculture will attract youth back to farms. Increasing the efficiency of small holder farmers by farm mechanization will be a challenge in the years to come. Public private partnership to promote mechanization of small farms to reduce crop production costs and post-harvest losses and boost crop output and farm income should receive priority.

Changing Scenarios/Operational environment: Urbanization, globalization, Trade:

Increasing globalization of agricultural trade will affect the profitability of different crops. Such impacts on the economy of rainfed crops, particularly oil seeds and pulses are already evident. With growing affluence and changing food habits per capita consumption of oil seeds, pulses etc will increase with further surge in imports. Therefore, more efforts on developing a favorable trade policy to encourage domestic production of these critical commodities will be needed.

Efficiency, equity and sustainability: Policy and institutions

The challenge of national and international agricultural development in the last century had revolved mainly around “food first” imperative. In the 21 st century the challenge transcends many objectives including increased agricultural productivity, poverty alleviation and economic growth and conserving natural resources. The complexities of the new challenges require reform in policies and institutions. The future policy should aim at bringing congruence between efficiency, equity and sustainability along with needed transformation in the organizational architecture. For example: the present land use and pricing policies (including subsidies and minimum price support) need relook. Policy and institutions must aim for convergence in different developmental programmes in terms of the focus, target areas and groups and efficiency of delivery. Creating a favourable environment supporting public-private partnerships in rainfed agriculture development will be a key challenge.

Opportunities:

Government of India has now given priority to rainfed agriculture through various agricultural and rural development schemes. For example, programmes like National mission on Sustainable agriculture (NMSA), MGNREGA, RKVY have identified several priority areas and have provision to facilitate adoption of rainfed agricultural development technologies. Also, several watershed development programmes implemented by the state governments incorporate improved technologies in their programs. The recent emphasis on pulses and oil seeds production also provides excellent opportunities to improve rainfed agriculture in India. The recent advances in modern science tools and techniques such as GIS, remote sensing, bioinformatics, nanotechnology, and information technology can be harnessed further to accelerate the development and transfer of improved technology in rainfed areas. For example, remote sensing and GIS tools can be used to demarcate boundaries for interventions within watersheds of different scale (micro catchment, basin etc.) along with the participation of the local communities.

Opportunities also exist to manage risks by diversifying farming systems. Integration of livestock production, practicing agri-horti systems by diversifying with fruit, fodder and fuel woods (agro forestry systems) etc and practicing collective or cooperative farming through farmer producer organizations will help in enhancing both productivity and risk aversion.

Some recently developed techniques and science tools which will provide greater opportunity to advance rainfed farm productivity and sustainability include:

- Conservation agriculture: Site specific and production specific conservation agricultural practices will provide opportunities for efficient conservation of resources and enhancing the productivity of systems

- Decision support systems and contingency planning: by continuous monitoring of weather events and providing crop advisories

- Agro-advisories and pest and disease forewarning

- Integrated systems and simulation modelling: to develop sustainable integrated systems and to help local governments to plan suitable adaptation and mitigation plans for emerging climate change challenges

- Remote sensing and GIS tools: to plan and monitor integrated watershed projects and land use planning. They are also extensively used for planning water harvesting structures and soil health and soil moisture mapping, and contribute to drought proofing

- Nanotechnology: can be exploited to develop variety of applications in rainfed agriculture such as improved seed germination, moisture conservation, nanofertilizers and for diagnostics for detection of plant stresses.

- Biotechnology and bioinformatics tools: to develop crops tolerant to multiple abiotic and biotic stresses.

- Information and Communication technology: to accelerate technology exchange and farm extension. Digital India programmes can be used to set up information kiosks and mobiles to cater the needs of stakeholders in rainfed areas.

The government of India's ambitious goal of doubling farm incomes in the coming five years can be achieved only if the rainfed farming productivity is improved significantly by harnessing the advances in science and technology.

Opportunities for Sustainable development: the need for a holistic approach

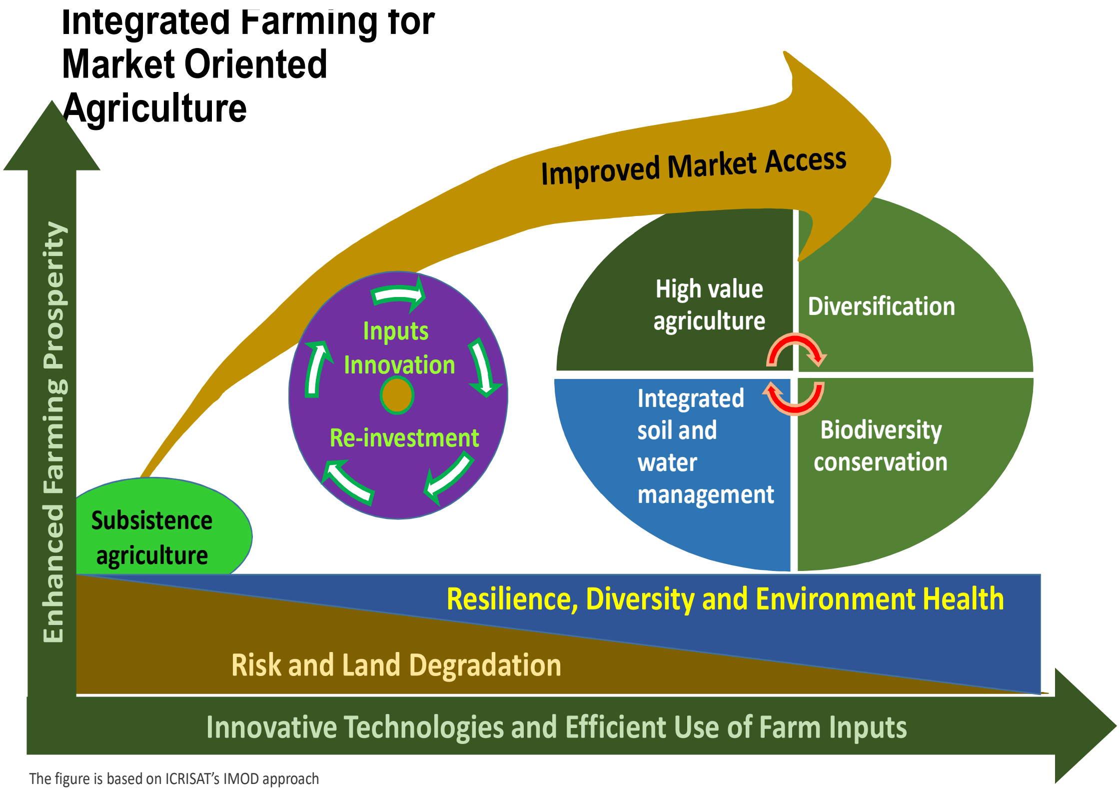
Rainfed agriculture has a critical role to play in achieving the UN's global sustainable development goals (UNSDG, 2030). Among the 17 SDGs targeted by the UN, those encompassing the social development (food security, malnutrition and health, education, women and youth etc.), environmental sustainability (sustainable use of water, soils, land and energy), economic growth (poverty alleviation, markets, trade, entrepreneurship), scientific innovations (ICT, genomics, mechanization) and climate change will provide much greater opportunities for rainfed agricultural development in the future. However, to address the many challenges as noted earlier, and to aim for an inclusive rural development and sustainable environment, alternative and holistic approaches are needed. Such alternative holistic approaches should build on partnerships across the whole agricultural value chains utilizing science backed interventions and follow the pathway to developmental impact.

In the past, the agricultural development was mainly aimed through specific commodity improvement and natural resources management, with limited attention on holistic solutions in an integrated manner. This approach resulted in rather slow adoption of improved technologies. Recently, some research and development efforts have been directed towards examining the whole agricultural value chain and identifying solutions to strengthen these value chains through improved technology and policy interventions. Still, efforts to combine the improved agricultural value chains (through component research and development) and sustainable and efficient use of resources are still in its infancy. Holistic solutions integrating social dimensions with sustainable intensification and building agribusinesses to achieve wider development impact have now been advocated by agricultural research and development organizations (ICRISAT, 2015). One such approach is described below:

Integrated market oriented rainfed agricultural development:

In 2008, the World Bank produced a comprehensive analysis of new trends in agriculture which is perhaps the most authoritative study ever developed on agriculture (World Bank, 2008). It narrated the history including the events of 1990s such as globalization, economic liberalization, structural adjustment, market deregulation etc., which contributed to industrial and urban development, but they hit the rural poor and small farmers hard. The marginal and small farmers were left on their own resulting in them not only food insecure but also poor. The report also established causal linkages between rural poverty and state of small farm agriculture in marginal areas and strongly advocated that agriculture should be developed to reduce poverty and accelerate economic growth. The study report's summary states" an emerging vision of agriculture for development redefines the roles of producers, the private sector and the state. Production is mainly by smallholders, who are most efficient producers particularly when supported by their organizations. The private sector drives the organization of value chains that brings the market to small farmers. The state corrects market failures, regulates competition and supports the greater inclusion of smallholders and rural workers. In this emerging vision agriculture assumes a prominent role in the development agenda ... and for implementing this vision the policy objective in agriculture for development should be to improve access to markets and establish efficient value chains". Utilizing this context of alternative vision for agricultural development, the global team of ICRISAT and its partners developed its new strategy for the decade 2011-20 called Inclusive Market oriented Development (IMOD). The centre piece of this new strategy is—that to escape hunger and poverty in the dry lands, small holder farmers needed to have better connections to markets.

Recently, several research and development organizations have been adopting the IMOD model in their strategy and action plans. A modified version of this alternative approach representing big picture of integrated and inclusive farming for market oriented rainfed agriculture as conceptualized by GRSV Consulting Services, 2016 is shown below:



The figure is based on ICRISAT's IMOD approach

The important element in the above diagram is the bold curve in the middle which represents the harnessing markets benefitting the small farmers and the rural poor, driving them from impoverished subsistence farming towards more prosperous market orientation. Conventional value chains don't have this focus on small and poor farmers, with only large farmers and the middlemen capturing most of the market access.

Underneath the curve is the rotating wheel which is the "engine of growth" that helps increasing the income of the small holders and rural poor. This dynamic engine of growth is "fueled" by the innovations (technologies) and investment (both private and public). Note that these innovations and investments are different than those found in conventional value chains which generally favor the better resource endowed large farmers and middle agents. Also, note that the investments refer to both physical inputs and socio-economic (including policy) interventions.

The third major dimension, the platform represented at the bottom of the diagram is on managing the risks that poor rainfed farmers face regularly. Managing the risks and enhancing the resilience is very important particularly for poor and small rainfed farmers because they have few resources to fall back on if something goes wrong. Diversification and conservation of biodiversity and appropriate land management practices to halt degradation are essential for risk management. For poor and subsistence farmers risk management also requires societal help through developmental assistance such as subsidies, credits and insurances, minimum support prices, emergency food reserves and other safety nets. Appropriate policy interventions are therefore critical not only to link small farmers to markets but also to encourage private sector to invest in rainfed agriculture development. It is also important to recognize that as the farmers' incomes increase through market linkages they become more and more resilient and stand on their own with minimal need for outside help and safety nets.

There are many more interesting angles to this alternative model of agricultural development. Just to mention a few: This model is dynamic and is a process of moving along the development pathway from hitherto static and impoverished subsistence farming to more prosperous market oriented and diversified agriculture. The model highlights the importance of both public and private interventions to pull farmers from poverty towards prosperity. The model also combines the development/prosperity dimension with sustainability (resilience, environmental health) and equity (risk aversion, inclusiveness).

Several factors determine the success of this alternative model of rainfed agricultural development. Some key factors include:

- Innovative institutional arrangements to link farmers to markets and end users (farm to fork, or plate to plough linkages)to reduce transaction costs and improve market efficiency: these include contract farming, direct marketing (bazaars and Sante), cooperative farming, farmers' associations, producers company and ICT enabled supply chains (Parthasarathy Rao, personal communication). The current initiatives would be successful only if the government creates a policy environment for scaling up and active public and private sector participation.

- Fostering agro-enterprises: by engaging private sector to accelerate the adoption and impact. More efforts on building agribusinesses through processing, facilitating market access, and driving market development are needed.

- Active public-private partnerships for holistic approach to development: To make bigger impact a consortium of all stakeholders working on a common platform contributing different skills towards development impact pathway is needed. Forming alliances with input and output traders and training youth and women in high value village based enterprises need to be intensified.

- Institutional reforms: To keep pace with the rapid global changes the present research and development institutions need to undergo a thorough review leading to concrete efforts to ensure new ways of doing business. The roles of various public institutions must be defined to avoid business as usual and duplication of efforts. The research and technology transfer institutions should work in sync and efforts should be made to encourage forming alliances with other private and public institutions.

Concluding remarks: Looking ahead

The government India and various state governments have now given high priority to agricultural development to reach the Prime Minister's vision of doubling farmers' income by 2022 through various development missions. They include National Mission for Sustainable Agriculture (horticultural mission, soil health card mission, pulses revolution etc), National Mission on Strategic knowledge on Climate Change, National Solar Mission, National Mission on Enhanced Energy Efficiency, National Water Mission and National Mission on Sustainable Habitat and also programs on subsidy support to farm insurance, minimum income and support pricing. Also, programs being implemented by various research and development organizations including ICAR, ICRISAT and Agricultural Universities will help developing the required technologies for rainfed agriculture development. The opportunities to improve rainfed agricultural productivity also exist through various other priority programmes such as enhancement of pulses and oil seeds production. A consolidated holistic approach with the convergence of these various government programmes at regional and local level will help in delivering desired outputs. There is a need to reform the agricultural technology management institutions to meet the new challenges by avoiding duplication and enhancing efficiency. Special emphasis is needed to use social science skills for scaling up research outputs into social outcomes and development impacts through appropriate policy interventions.

Considering the growing vulnerabilities of rainfed agriculture to climate change, mitigation and adaptation strategies to build resilience should receive high priority. Designing climate smart agriculture coupled with enhancing farmer income through market linkage should be the central focus in the years ahead. A mission mode approach by bringing all the stakeholders including the public and private sectors with expertise across the whole rainfed agricultural value chain together on a common platform is necessary for inclusive sustainable development. Many technological advances for profitable agriculture are now in place, but scaling up these advances into a wider and sustainable rural development in rainfed areas should be the common goal. The use of ICT in technology transfer will help in achieving the vision of digital agricultural revolution.

The international and national research organizations continue to address critical and evolving challenges to rainfed agriculture through strategic and applied research using frontier tools. The regional and local institutions should form consortia to undertake action research and evolve location specific innovations and technology dissemination. The bio-physical and social scientists together should guide the policy makers in undertaking appropriate policy reforms and provide safety nets for wider scale adoption towards enhancing the livelihood security and sustainable development in rainfed farming areas.

Goal 1 and 2 of the UN Sustainable development goals envision eradicating poverty and hunger by 2030. Adopting sustainable business models along with appropriate innovations and partnerships in rainfed agriculture is crucial for achieving these goals.

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