Climate Change and Sustainable Rain-fed Agriculture : Challenges and Opportunities

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Introduction

Climate is usually defined as the average weather or more rigorously as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The term climate change refers to a statistically significant variation in either the mean stage of the climate or in its variability, persisting for an extended period (typically decade or longer). Climate change may be due to natural internal processes or external forcing, or to persistent anthropogenic changes in the composition of the atmosphere or in land use. The fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC) confirms that the global average temperature increased by 0.74°C over the last 100 years; and the projected increase in temperature by 2100 is about 1.8 to 4.0°C. Global warming poses a potential threat to agricultural production and productivity throughout the world and this might affect the crop yields, incidence of weeds, pests and plant diseases and the economic costs of agricultural production. Crop productivity is projected to decrease even by small rise in temperature (1-2°C) at the lower latitudes, especially in the seasonal dry and tropical regions (IPCC, 2007). In India in understanding the nature of and magnitude of yield gains and losses of crops at selected sites under elevated atmospheric CO_2 and associated climate change, Sinha and Swaminathan (1991) reported that integrated impact of rise in temperature and CO_2 concentration on crops yield may be negative. They estimated that a 2°C increase in air temperature could decrease rice yield by about 0.75 tons ha^{-1} in high yielding areas. The CERES-sorghum simulated results indicated a decrease in yield and biomass of rainy season sorghum at Hyderabad and Akola under all climate change scenarios. The positive effect of increased CO_2 if any, were masked by the adverse effects of predicted increase in temperature, resulting in shortened crop growing seasons (Gangadhar Rao *et al.*, 1995). Aggarwal (2003) reported that in north India, irrigated wheat yields are decreased as the temperatures increase and a 2°C increase resulted in a 17 per cent decrease in grain yield and with the further increase in temperature the decrease in yield was very high. Atmospheric CO_2 concentration has to rise to 450 ppm (parts per million) to nullify the negative effect of 1°C rise in temperature. So the effect of climate change scenario of different periods can be positive or negative, depending upon the magnitude of change in atmospheric CO_2 and temperature. The highest decrease in chick pea grain yield per degree rise in the Rabi season temperature was observed in Haryana (3.01 q ha^{-1}), followed by Punjab (1.81 q ha^{-1}), Rajasthan (1.27 q ha^{-1}) and Uttar Pradesh (0.53 q ha^{-1}) (Kalra *et a.*, 2008). It was further indicated that due to climate change, there is reduction in crop yield of 10 to 40 per cent at .the present yield level by the turn of the century.

Millennium Development Goal (MDG) presents a formidable challenge on the other hand, not only targeting to halve the hungry by 2015, but also to produce more food in the developing world, more water needs to be appropriated for crop and livestock. Assuming a balanced dietary consumption requiring 1,300 m^3 cap^{-1} y^{-1}, an additional 2,200 m^3 y^{-1} is needed to achieve the MDG target on hunger by 2015. To eradicate undernourishment by 2030 corresponds to 4,200 m^3 y^{-1}, reaching 5,200 m^3 y-l by 2050 for additional water for crop and livestock production. Water productivity improvements are essential to reduce pressure on water resources. If we assume improved water productivity from 1,800 m^3 to 1,200 m^3 per ton of grain produced, the corresponding required water for meeting MDG by 2015 means considerable additional water demand. The estimated additional water requirements, allowing for water productivity improvements, are of the order of 1,850 km^3 y^{-1} in 2015, to about 3,000 m^3 y^{-1} in 2030. This additional requirement presents a great challenge, when we consider the need to allocate water resources for domestic and purposes other than agricultural production (SEI, 2005). It is therefore important, to develop a long-term strategy to cope with the climate change and its adverse effects including higher temperatures, drought and floods. With climate change, the existing water scarcity is likely to be exacerbated and there is an urgent need to manage efficiently the available water resources. The main objective of this paper is to present the current status and production potential of rain-fed agricultural and to suggest measures

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to minimize the adverse impacts of climate change on our goal to achieve food security through sustainable increase in agricultural production in rain-fed areas.

Importance of Rain-fed Agriculture

Globally, rain-fed agriculture is very important as 80 per cent of the world's agricultural land area is rain-fed and generates 58 per cent of the world's staple foods (SIWI, 2001). Most food for poor communities in the developing countries is produced in rain-fed areas. For example, in sub-Saharan Africa (SSA), more than 95 per cent of the farmed land is rain-fed, while the corresponding figure for Latin America is 90 per cent, for South Asia it is about 60 per cent, for East Asia 65 per cent and for Near East and North Africa 75 per cent. About half of the hungry live in smallholder farming households, while two-tenths are landless. About 10 per cent are pastoralists, fish folk and forest users (Sanchez et al, 2005). In the developing countries in the semi-arid tropics (SAT), poverty is concentrated more in the rain-fed areas (Ryan and Spencer, 2001). In India, 60 per cent of 142 million ha arable land is rain-fed. In addition to vast areas covered by rain-fed agriculture, these areas are also the hot spots of poverty, malnutrition and child mortality. Most of the 852 million hungry and malnourished people in the world are in Asia, particularly in India (221 million) and in China (142 million). In Asia, 75 per cent of the poor are in the rural areas and they depend on agriculture for their livelihood. Rain-fed agriculture becomes important not only because of large areas but also from social and equity concerns for improving the livelihoods of a large number of people to meet the MDGs of reducing the number of poor by half by 2015.

Current Status of Rain-fed Agriculture

An insight into the rain-fed regions shows a grim picture of water-scarcity, fragile ecosystem, drought and land degradation due to soil erosion, by wind, water and nutrient mining, low rainwater use efficiency (35-45 per cent), high population pressure, poverty, low investments in water use efficiency measures, poor infrastructure and inappropriate policies (Wani et al, 2003a, Rockstrom et al, 2007). Drought and land degradation are interlinked in a cause and effect relationship and both in turn are the causes of poverty. This unholy nexus between drought, poverty and land degradation has to be broken, if we have to meet the MDG of halving the number of food insecure poor by 2015. Land degradation due to accelerated erosion resulting in the loss of nutrient rich top fertile soil however, occurs nearly everywhere where agriculture is practiced and this can be irreversible. The torrential character of the seasonal rainfall creates high risk for the cultivated lands. In India alone, some 150 million ha are affected by water erosion and 18 m ha by wind erosion. Thus, erosion leaves behind an impoverished soil on one hand and siltation of reservoirs and tanks on the other. In addition to imbalanced use of nutrients in agriculture, farmers exploit the soil nutrient reserves. For example in the SAT India, a large number of on-farm trials conducted in more than 300 villages demonstrated that the current subsistence agricultural systems have depleted soils not only of the macro-nutrients but also of secondary nutrients such as sulfur and micronutrients such as zinc and boron. Widespread deficiencies of micro and secondary nutrients were observed in farmers' fields in various states of the SAT India (Table 4). If these resources are not managed properly the impact of climate change will further deteriorate these resources and the potential of the environments for agricultural production. Moreover, investments in the rain-fed agriculture pose serious challenges, as the large numbers of households are small, with marginal farmers having no resources to invest and poor infrastructure facilities. The knowledge intensive extension effort needed in the rain-fed areas suffers from limited information on the options available, social and economic constraints to adoption, lack of enabling institutions and policies (environments) and backup services, poor market linkages, weak infrastructure and low means to pay.

Potential of Rain-fed Agriculture

In tropical regions, particularly in the sub-humid and humid zones, agricultural yields in commercial rain-fed agriculture exceed 5-6 t ha^{-1}. However, farmers' crop yields are in the region of 0.5 - 2 t ha^{-1}, with an average of 1 t ha^{-1} in sub-Saharan Africa and 1-1.5 t ha^{-1} in the SAT Asia and the Central and West Asia and North Africa (CWANA) regions for rain-fed agriculture (Rockstrom and Falkenmark, 2000; Wani et al. 2003a, b). Yield gap analyses, undertaken by the Comprehensive Assessment, for major rain-fed crops in semi-arid regions in Asia and Africa and rain-fed wheat in West Asia and North Africa (WANA), reveal large yield gaps, with farmers' yields being a factor 2 - 4 lower than achievable yields for major rain-fed crops grown in Asia and Africa (Rockstrom et al. 2007). In India and other countries large yield gaps for all the major rain-fed crops have been observed and with the available technologies crop yields can be easily doubled (Fig. 1). Evidence from long-term study at the ICRISAT center, Patancheru, India, since 1976, demonstrated that through improved land, water and nutrient management in rainfed agriculture, sorghum/ pigeonpea intercrop system produced higher mean grain yields (5.1 t ha^{-1} yr^{-1}) compared to 1.1 t ha^{-1} yr^{1} under the traditional system where crop is grown on stored soil moisture with the application of 5 t ha^{-1} FYM once in two years. The annual gain in grain yield in the improved system was 82 kg ha^{-1} per year compared to 23 kg ha^{-1} per year in the traditional system (Fig. 2).

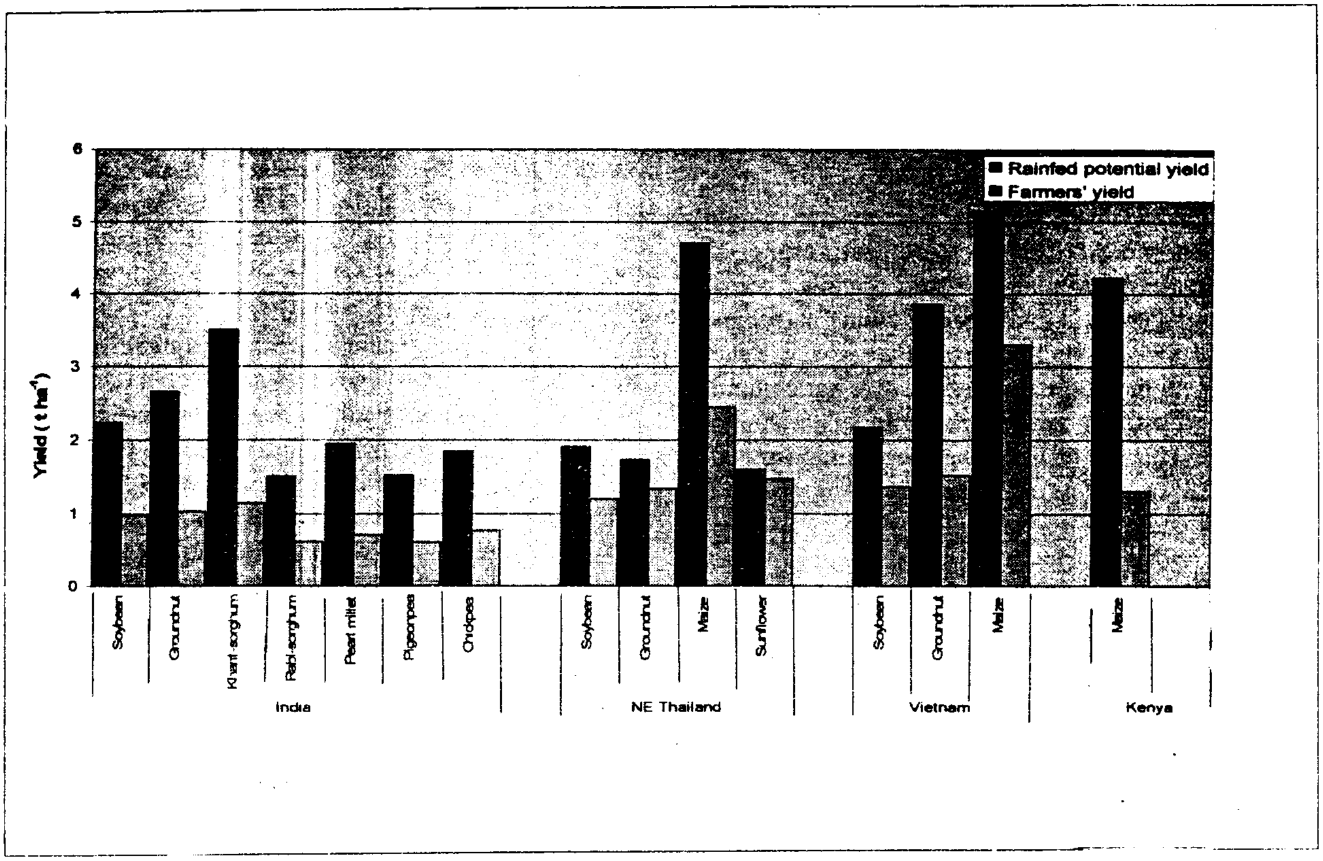

Figure 1. Yield gap analysis of important rain-fed crops in different countries.

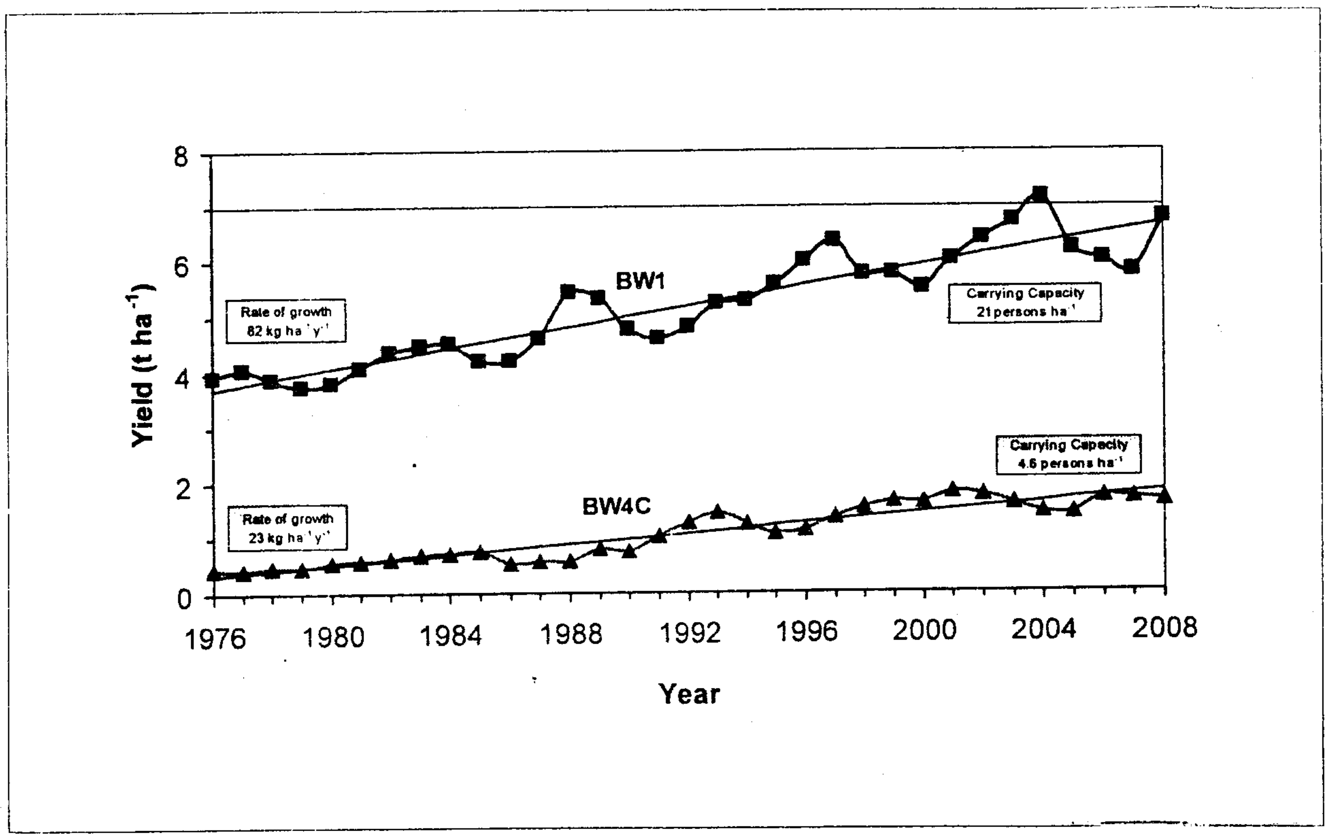

Figure 2. Three-year moving average of crop yields in improved and traditional management systems during 1976-2006 at ICRISAT, Patancheru, India.

Unless appropriate adaptation and mitigation measures are taken, it will be difficult to achieve such higher yield to bridge the yield gaps under climate change scenarios [With growing water scarcity and increasing degradation of natural resources]

Vulnerability to Climate change Impacts

Climate change is real and its implications are going to be borne by the poorest of the poor. If climatic change is accompanied by an increase in climate variability, many agricultural producers will experience definite hardships and increased risk. The SAT regions, which have economies largely based on weathersensitive agricultural productions systems, are particularly more vulnerable to climate change. This vulnerability has been demonstrated by the devastating effects of recent flooding and the various prolonged droughts during the twentieth century. Thus for many poor countries that are highly vulnerable to effects of climate change, understanding farmers' responses to climatic variation is crucial in designing appropriate coping strategies to climate change. The impact can be reduced through lessening the human impacts on the atmosphere and the climate through emission reductions and adapting to live with a changing climate before the results of mitigation can begin to appear. The integrated watershed development approach could be the option for reducing the future climate change impact by increasing water and nutrient use efficiencies reducing land degradation and reducing risk through farming system diversification in the rain-fed agriculture.

Continued population growth and predicted climate change exert pressure on agricultural out put to meet food demand of people. Without considering the potential impact of climate change, the deficit of cereal production is higher in Asia (135 Mt), followed by West Asia and North Africa (83 Mt), China and Sub-Saharan Africa during 2025 compared with current deficit in Asia and Africa regions if the current 'business as usual', rain-fed resource management and investment policies are maintained (Table 1)

TABLE 1—CURRENT AND PREDICTED CEREAL PRODUCTION AND DEMAND IN ASIA AND AFRICA

Country/ Region	Current status (million tons)			Predicted status in 2025 (million tons)[a]		
	Production	Demand[b]	Deficit	Production*	Demand	Deficit
Asia	726	794	68	1093(30)	1228	135
China	358	375	17	542(26)	581	39
India	175	171	Surplus 4	257(31)	275	18
S.E.Asia	106	114	8	170(47)	176	6
South Asia (Except India)	51	55	4	81(14)	102	21
Sub-Saharan Africa	69	78	9	137(88)	172	35
West Asia and North Africa	82	120	38	119(54)	202	83

a—Predicted values for the period 2021-2025 according to a 'business as usual' scenario which assumes the continuation of population growth patterns and current trends of and existing plans in water and food policy, resource management and investment, but does not considered the potential impact of climate change.

b—The sum of food and feed demand.

*—Figures in parenthesis are the predicted percentage of total cereal production in 2025 from rain-fed.

In this scenario, policies must be put in place and decisions taken to greatly accelerate the current trends of investment in the rain-fed agriculture sector beyond the 'business as usual' scenario upon which such projection are based. In the Asia region, the predicted population in the medium growth scenario is about 700 million people (about equal to the current population of Europe) in the next 30 years. This will result in a greater demand for food and it is estimated that the foodgrain requirement by 2020 in the region will be almost 50 per cent more than that of the present (Paroda and Kumar, 2000) (Table 2). On the other hand due to climate change, the food production is going to be reduced in this region considerably in 2020 and around 10-40 per cent reduction at the turn of the century. The additional food will have to be produced from the same or less land resources due to increased competition for land and other resources from non-agricultural sectors. So, the increasing food demand of the population has to be met under the impact of climate change and a greater competition for the natural resources from the non-agricultural sectors.

TABLE 2—PROJECTED DEMAND FOR FOOD IN SOUTH ASIA FOR 2010 AND 2020 ASSUMING A 5 PER CENT GDP GROWTH AND CONSTANT PRICES.

Items	Production(Mt)	Demand for food (Mt)	
	1999-2000	2010	2020
Rice	85.4	103.6	122.1
Wheat	71.0	85.8	102.8
Coarse grains	29.9	34.9	40.9
Total cereals	184.7	224.3	265.8
Pulses	16.1	21.4	27.8
Foodgrains	200.8	245.7	293.6
Fruits	41.1	56.3	77.0
Vegetables	84.5	112.7	149.7
Milk	75.3	103.7	142.7
Meat and eggs	3.7	5.4	7.8
Marine products	5.7	8.2	11.8

Source : Paroda and Kumar, 2000

Impacts of Climate Change on Rain-fed Agriculture

Any perturbation in agriculture can considerably affect the food systems and thus increase the vulnerability of a large fraction of the resource-poor population. Increase in CO_2 concentration will have beneficial effect on crops especially the legumes (C_3 species) by increasing photosynthesis rate. Increase in temperature in the tropical regions will reduce crop productivity by reducing length of growing season and crop duration (faster crop development, thereby using less natural resources), direct adverse effect on crop growth and yield formation and by increasing water stress in plants as a result of increased water demand along with increased frequency of drought occurrence. Unless the change in rainfall is substantial, slight increase or decrease in rainfall will have a marginal effect on crop yields. Crop simulation analysis for *kharif* sorghum using DSSAT at Parbhani showed that a temperature increase of 3.3 °c, which is expected to increase by the end of this century, will on an average reduce the crop yield under good management by 27 per cent. However, the effect of 11 per cent increase in rainfall will be marginal (Fig. 3). Despite variable response across seasons to increase in temperature, an average yield reduction of groundnut crop at Anantapur will be about 38 per cent and an increase in rainfall will benefit the crop marginally (Fig. 4). Considering the impacts of increase in temperature and CO_2 concentration, the yield reduction of rain-fed crops across a few selected locations in India are simulated to be 22 to 50 per cent for *kharif* sorghum, 33 to 51 per cent for pearl millet, 23 to 29 per cent for groundnut, 8-11 per cent for pigeonpea and 7 per cent for chickpea (at Nandyal and Akola). Because of current low temperatures during the season at Guna (Madhya Pradesh) climate change is expected to increase the chickpea yield by about 9 per cent. However, the climate change impacts at current low levels of management of crops would be marginal (Piara Singh, unpublished data). This means that as we improve the management of crops to achieve higher crop yields to achieve food security the impacts of climate change will become significant.

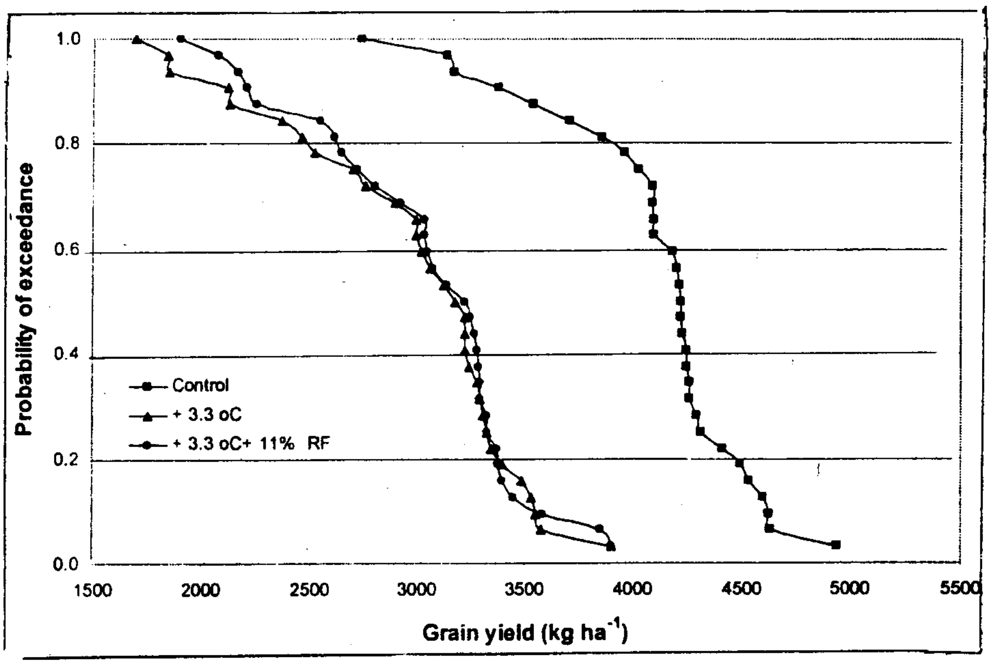

Figure 3. Probability distribution of Kharif sorghum yield under climate change at Parbhani.

Due to climate change, the absolute water stress is most notable in the arid and the semi-arid regions with high population densities such as parts of India, China and the Middle East/North Africa (MENA) region. The MENA region is increasingly unable to produce the food required locally due to increasing water stress from a combination of population increase, economic development and climate change and will have to rely more and more on food imports. So there is a need to identify the potential water productivity method to overcome the impact of climate change and achieve the MDGs as well.

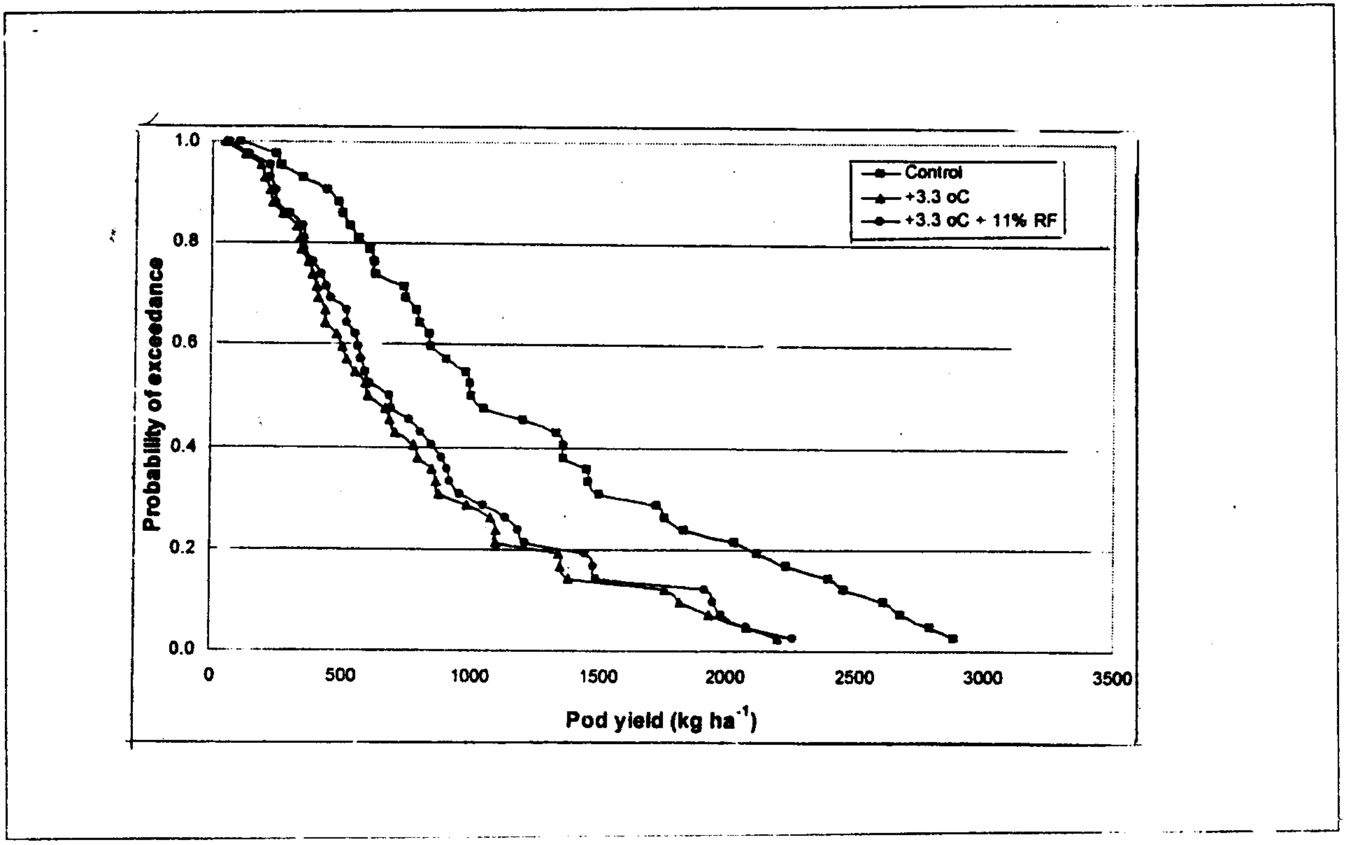

Figure 4. Probability distribution of groundnut yield under climate change at Anantapur.

Strategy for Sustainable Agriculture to Minimize Impacts of Climate Change

The agriculture in the 21st century faces multiple challenges— by the need to produce more food to fulfil the requirement of rapid growing population and growing incomes on one hand, along with the yield reduction due to climate change on the other. So, the business as usual is no longer an option to achieve the food security with growing population, depleting natural resources (land degradation and water scarcity) and suitable long-term coping strategies need to be developed urgently to overcome the impacts of climate change to achieve food security. Farmers in particular and the society in general have always attempted to adopt to climatic stresses by restoring to mixed cropping, changing varieties and planting times and by diversifying their sources of income. In future, such adaptation strategies would need to be considered along with the changing demand due to globalization and population increase and income growth, as well as the socio-economic and environmental consequences of possible adaptation options.

It is hypothesized that "with medium term (2010-2050) ICRISAT is well placed to help farmers mitigate the challenges and exploit the opportunities that are posed by climate change through: (i) the application of existing knowledge on crop, soil and water management innovations and (ii) the re-deployment and retargeting of the existing germplasm of its mandate crops. While much work initiated remains to be completed, early outputs support the hypothesis. Climate change will modify the length of the growing period across the regions of interest, but that this can in large part be mitigated by the re-targeting and re-deployment of the existing germplasm of the crops and by managing rainwater through conservation and harvesting. A schematic framework for testing our hypothesis is presented in Figure 5. The framework identified three yield gaps that ICRISAT must address in seeking solutions.

Current Climate Yield Gap:

Column 1 (Fig. 5) in the schematic represents yields that farmers are getting under their current and relatively low input management. Column 5 represents the yields that farmers could get through the adoption of current simple and affordable recommendations for improvements in variety choice and crop, soil, nutrient and water management practices. This is the yield gap that ICRISAT is currently addressing.

Yield Gap 1:

Column 2 (Fig. 5) represents the marginally decreased yields that farmers would get under climate change if they were to continue using the same low-input system. We have shown that under such low input systems, factors other than climate change continue to provide the overriding constraint. Column 3 represents the yields that farmers could get, even under climate change, if they adopted current improved practice recommendations. This is the yield gap that ICRISAT is and will continue to address through our work to develop, scale up and scale out enhanced crop, soil, nutrient and water management options for farmers in the semi-arid tropics.

Yield Gap 2:

Column 4 (Fig. 5) represents the yields that farmers could get under climate change if they were to adopt current improved practice recommendations together with developed cultivars better adapted to a warmer world.

Within the scope of the *ex-ante* analyses that we have done so far, we consider better adaptation solely constitute varieties whose maturity length is better suited to growing in a warmer world. We recognize that other factors such possible changes in rainfall patterns and in the distribution of pests and diseases will also have to be considered. This is the yield gap that ICRISAT will be addressing through our work to develop and deliver improved crop varieties with enhanced performance under high CO_2 concentrations, high temperatures and erratic rainfall conditions for farmers in the semi-arid tropics.

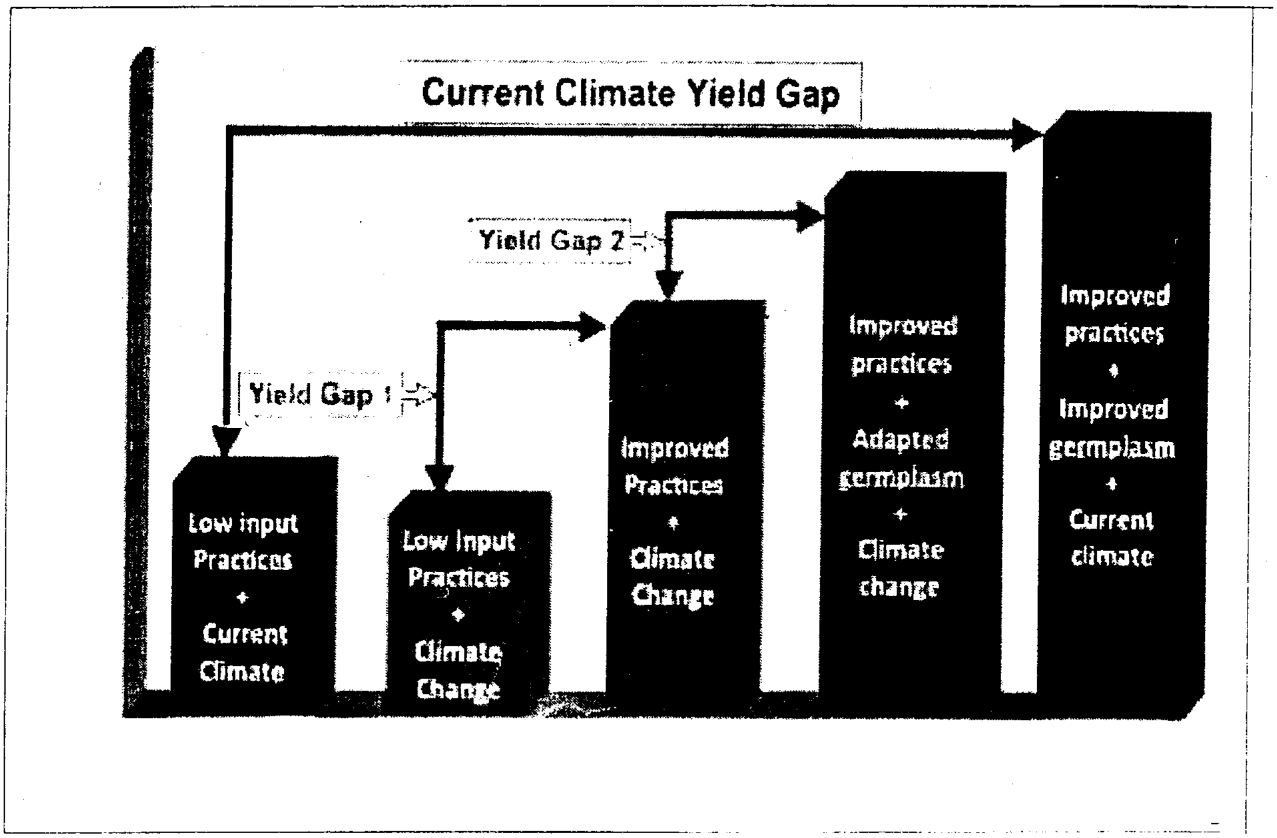

Figure 5. Hypothesis of Hope" Schematic Framework.

The further step is the use of simulation models that integrate the impact of variable weather with a range of soil, water, nutrient and crop management choices. Such simulation models, driven by daily climatic data, can be used to predict the impact of existing climatic variability on the probability of success of a range of crop, water, nutrient and soil management strategies. The use of such models, with long runs (30 years or more) of daily climatic data provides a quick and much less costly opportunity of accelerated learning compared with the more traditional multi-location, multi-seasonal and multi-factorial field trials.

Science-based IGNRM Approach

Traditionally, crop improvement and NRM were seen as distinct but complementary disciplines. ICRISAT is deliberately blurring these boundaries, to create the new paradigm of Integrated Genetic and Natural Resource Management (IGNRM). Improved varieties and improved natural resource management are two sides of the same coin. Most farming problems require integrated solutions, with genetic, management-related, socio-economic and policy components. In essence, plant breeders and NRM scientists must integrate their work with that of private and public sector change agents, to develop flexible cropping systems that can respond to rapid changes in market opportunities and climatic conditions. The systems approach looks at various components of the rural economy - traditional foodgrains, new potential cash crops, livestock and fodder production, as well as socio-economic factors such as alternative sources of employment and income. Appropriate management of natural resources is the key to good agriculture. This is true everywhere - and particularly in the SAT, where over-exploitation of fragile or inherently vulnerable agro-ecosystems is leading to land degradation, productivity decline and increasing hunger and poverty. Modern crop varieties offer high yields but the larger share of this potential yield can only be realized with good crop management (Fig. 6). The results depicted in Figure 6 demonstrated that improved varieties alone cannot bridge the yield gap and integration of improved natural resource management is must to harness the potential of rainfed agriculture in the SAT (Wani et al. 2009).

ICRISAT, working under a vast and diverse mandate area, has learned one key lesson: that technologies and interventions must be matched not only to the crop or livestock enterprise and the biophysical environment, but also with the market and investment environment, including input supply and policy. Various NRM technologies have been developed over the years—but adoption has been poor for various reasons, technical, socio-economic and institutional. ICRISAT, is also working on the strategy to reduce the greenhouse gas (GHG) emissions through the use of biological nitrification inhibition (BNI) and by improving nutrient use efficiency and water use efficiency (irrigation and rainfall use efficiency), of production systems. Similarly, increased C-sequestration strategies using legume-based crop diversification along with improved soil, water and nutrient management options described later in this paper (Wani et al. 2008 ab).

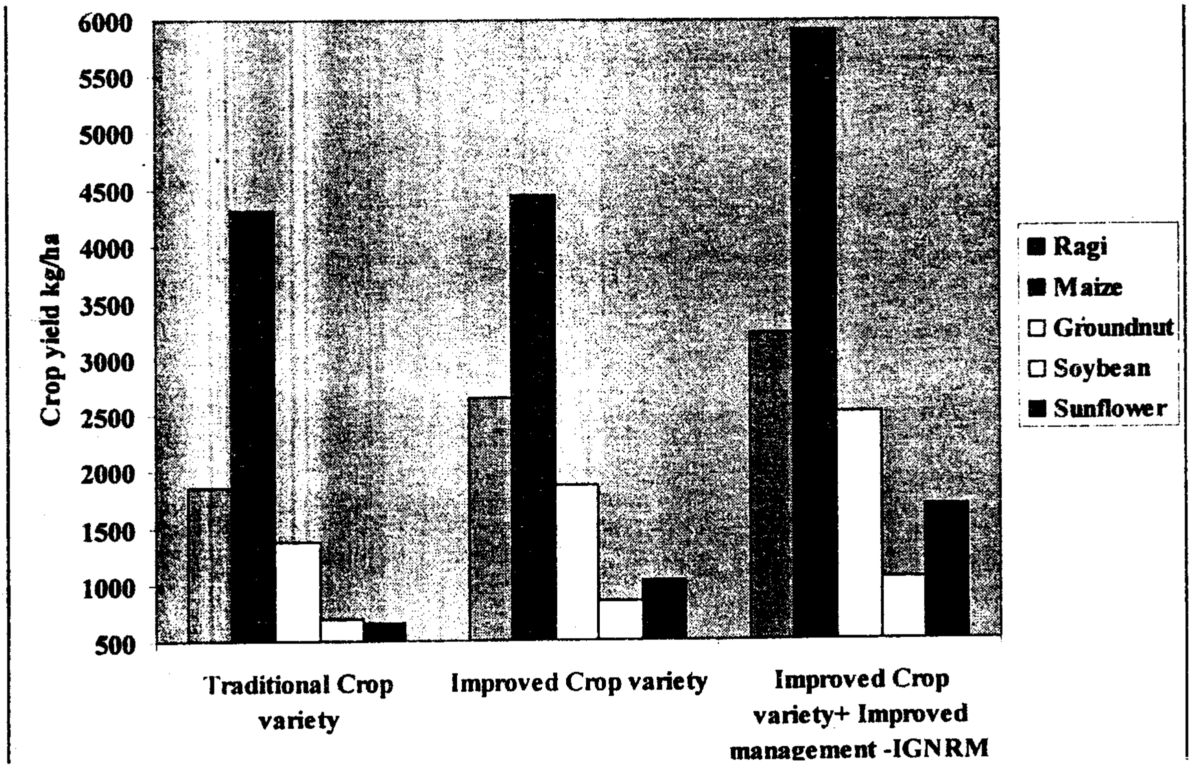

Figure 6. Contribution of different technology components on average crop yields, observed in on-farm trials in 14 Sujala micro watersheds in six districts of Karnataka Average of on-farm trials conducted in Karnataka.

Improved Water Management

Water scarcity is a relative concept and there are various indicators and thresholds of water scarcity. Although, the global amount of renewable fresh water has not changed, the amount available per person is much lower than what it was in 1950, due to population growth and increasing demands on available resources. Water is not equally distributed throughout the world and impacts of climate change will vary among regions. The increasing water scarcity resulting from population growth, rising incomes and climate change, limits the amount of water available for food production and threatens food security in many countries. As the world's population grows and incomes rise, farmers will —if they use today's methods — need a great deal more water to feed the population: another 1600 km^3 yr^1 just to achieve the UN Millennium Development Goals of halving hunger by 2015 (SEI. 2005) and another 4500 km^3 yr^1 with current water productivity levels in agriculture to feed the world in 2050 (Falkenmark *et al.*, 2009; Rockstrom et al., 2009). This is more than twice the current consumptive water use in irrigation, which already contributes to depleting several large rivers before they reach the ocean. It is becoming increasingly difficult, on social, economic and environmental grounds, to supply more water to farmers.

Frequent scarcity of water well illustrated by the studies by ICRISAT in India over a 25 year period. In Aurepalle and Dokur in Andhra Pradesh, our studies reveal the acute effects of persistent drought and increasing water scarcity on livelihood strategies (Singh et al. 1985). Almost all dug wells in both villages have dried up and village irrigation tanks (previously filled through run off) have not filled in a decade. Farmers are now forced to leave much of their land fallow and the percentage income derived from agricultural related activities has declined dramatically from 88 to 47 per cent in Aurepalle and from 94 to 35 per cent in Dokur. However, farm families have successfully adapted and diversified their livelihood strategies through increased off-farm activity, caste occupations and seasonal job migration. Indeed, in real terms, they have higher incomes today as a result. In other words the communities in these two villages have had high adaptive capacity.

However, whereas these households have adapted to the changes triggered by recurrent drought through diversification onto off-farm activities, this may not be a feasible alternative for many smallholder farmers in the isolated and less-favored areas of rain-fed system in Africa and Asia. There is a great need to develop options and innovations that enhance the resilience of the agricultural production system and reduce the vulnerability to such shocks. ICRISAT's experience on the watershed management in India is one such example. The combined effects of enhanced crop tolerance to drought, integrated management of land and water resources and improved water productivity has reduced the vulnerability to climate shocks and also improved productivity. This is illustrated in Kothapally village. Integrated watershed management has contributed to improving the resilience of agricultural incomes despite the high incidence of drought. While drought induced shocks reduced the average share of agricultural income (as per cent of the total household income) in nearby non-project village from 44 to 12 per cent, this share remained unchanged at about 36 per cent in the adjoining watershed project village of Kothapally (Shiferaw et al. 2006).

Since 1990's, there has been a paradigm shift in the thinking of policy makers based on the learning from the earlier watershed programmes. Detailed evaluation of on-farm watershed programmes implemented in the country, ICRISAT team observed that once the project team withdrew from the villages, the farmers reverted back to their earlier practices and very few components of the improved soil, water and nutrient management options were adopted and continued. Although, economic benefits of the improved technologies were observed in the on-farm studies, the adoption rates were low. Individual component technologies such as summer ploughing, improved crop varieties and intercropping however were continued by the farmers. However, soil and water conservation technologies were not much favoured (Wani et al., 2002b).

Meta-analysis of 311 watershed case studies from different agro-eco regions in India revealed that watershed programmes benefited farmers through enhanced irrigated areas by 33.5 per cent, increased cropping intensity by 63 per cent, reducing soil loss to 0.8 t ha^{-1} and runoff to 13 per cent and improved groundwater availability. Economically the watershed programmes were beneficial and viable with a benefit—cost ratio of 1:2.14 and the internal rate of return of 22.0 per cent (Joshi et al. 2005). However, about 65 per cent of the case studies showed below average performance (Table 3). Better performance of watersheds were realized in the rainfall regime of 700-1000 mm. There is a need to develop technologies to the area falling in the rainfall regime of < 700 mm and > 1000 mm.

TABLE 3—BENEFITS OF WATERSHEDS—SUMMARY OF META-ANALYSIS

Indicator	Particulars	Unit	No. of studies	Mean	Mode	Median	Min.	Max.	t-value
Efficiency	B/C ratio	Ratio	128	2.14	1.70	1.8	0.8	7.1	21.25
	IRR	Per cent	40	22.0	19.0	16.9	1.7	94.0	6.54
Equity	Employment	Person days ha^{-1} yr^{-1}	39	181.5	75.0	127.0	11.0	900.0	6.74
Sustainability	Irrigated area	Percent	97	33.6	52.0	26.0	1.4	156.0	11.77
	Cropping intensity	Per cent	115	63.5	80.0	41.0	10.0	200.0	12.65
	Rate of runoff	Per cent	36	-13.0	-33.0	-11.0	-1.3	-50.0	6.78
	Soil loss	Tons ha^{-1} Yr^{-1}	51	-0.8	-0.9	-0.9	-0.1	-0.99	39.29

Integrated Watershed Development to Enhance Productivity and Resilience

Watersheds are not only hydrological units but provide life support to rural people by making people and animals an integral part of watersheds. Activities of people/animals affect the productive status of watersheds and *vice versa*. Currently there is a vicious cycle of 'poverty—poor management of land and crop — poor soils and crop productivity - poverty' is in operation in most of the watersheds. This results in a strong nexus between drought, land degradation and poverty. Appreciating this fact, the new generation of watershed development programmes is implemented with a larger aim to address issues of food security, equity, poverty, severe land degradation and water scarcity in dry land areas. Hence, in the new approach, watershed, a land unit to manage water resources has been adopted as a planning unit to manage natural resources of the area. Improving livelihoods of local communities is highlighted by realizing the fact that in the absence of them, sustainable N RM would be illusive. Due to these considerations watershed programmes have been looking beyond soil and water conservation into a range of activities from productivity enhancement through interventions in agriculture, horticulture, animal husbandry to community organization and gender equity. This holistic approach required optimal contribution from different disciplinary backgrounds creating a demand for multi-stakeholder situation in watershed development programmes.

Based on the learning from the meta-analysis and earlier on-farm watersheds ICRISAT in partnership with national agricultural research systems (NARSs) developed and evaluated an innovative farmers participatory integrated watershed consortium model for increasing agricultural productivity and later for improving rural livelihoods (Wani et al. 2003b). The conventional watershed approach is compartmental, structure-driven and lacks the strategy for efficient resource use. Though watershed serves as an entry point, a paradigm shift is needed from these traditional structure-driven watershed programmes to a holistic systems' approach to alleviate poverty through increased agricultural productivity by environment-friendly resource management practices (Wani *et al.* 2003b, 2008a, b). Watershed, as an entry point should lead to exploring multiple livelihood interventions/options (Wani et al. 2006, 2007a, 2008) and the new community watershed management model fits into the framework as a tool to assist in the sustainable rural livelihoods.

ICRISAT's consortium model for the community watershed management espouses the principles of collective action, convergence, cooperation and capacity-building (4Cs) with technical backstopping by a consortium of institutions to address the issues of equity, efficiency, economics and environment (4Es). The new integrated community watershed model provides technological options for management of runoff water harvesting, waterway systems, in-situ conservation of rainwater for groundwater recharging and supplemental irrigation, appropriate nutrient and soil management practices, crop production technology and appropriate farming systems with income-generating micro-enterprises for improving livelihoods while protecting the environment (Wani et al. 2002, 2006, Sreedevi et al. 2004). The water alone can not improve the productivity of crops in rain-fed areas and proper soil, crop, nutrient and pest management options are essential to improve productivity in these areas.

Soil Health : An Important Driver for Enhancing Water Use Efficiency in Rain-Fed Areas

Soil health is severely affected by land degradation and is in need of urgent attention. ICRISAT's on-farm diagnostic work in different community watersheds in different states of India as well as in China, Vietnam and Thailand showed severe mining of soils for essential plant nutrients. Exhaustive analysis showed up to 80-100 per cent farmers' fields were deficient not only in total nitrogen but also micronutrients like zinc, boron and secondary nutrients such as sulphur (Table 4). In addition, soil organic matter an important driving force for supporting biological activity in soil, is low particularly in tropical areas. Management practices that augment soil organic matter and maintain at a threshold level are needed. Farm bunds could be productively used for growing nitrogen-fixing shrubs and trees to generate nitrogen-rich lopping. For example, growing Glyricidia sepium at a close spacing of 75 cm on farm bunds could provide 28-30 kg nitrogen per ha in addition to valuable organic matter. Also, large quantities of farm residues and other organic wastes could be converted into valuable source of plant nutrients and organic matter through vermicomposting (Wani *et al.* 2005).

Strategic long-term catchment study at the ICRISAT center showed that the legume-based systems particularly with pigeonpea could sequester 330 kg carbon up to 150 cm depth in Vertisols at Patancheru, India under rain-fed conditions (Wani et al. 2003a). Under National Agricultural Technology Project (NATP), ICRISAT, National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), Central Research Institute for Dryland Agriculture (CRIDA) and Indian Institute of Soil Science (IISS) have identified carbon sequestering systems for Alfisols and Vertisols in India (ICRISAT, 2005, Wani et al. 2007b).

TABLE 4—PERCENTAGE OF FARMERS' FIELDS DEFICIENT IN SOIL NUTRIENTS IN DIFFERENT STATES OF INDIA

State	No. of farmers' fields	OC (per cent)	Available nutrients (mg kg^{-1} soil)				
			P	K	S	B	Zn
Andhra Pradesh	1926	85	41	12	89	88	82
Karnataka	11609	70	48	24	85	74	52
Madhya Pradesh	341	22	74	1	74	79	66
Rajasthan	421	38	45	15	71	56	46
Gujarat	82	12	60	10	48	100	85
Tamil Nadu	119	57	51	24	71	89	61
Kerala	28	11	21	7	96	100	18
Total	14526						

OC = Organic Carbon

Often, soil fertility is the limiting factor to increased yields in rain-fed agriculture (Stoorvogel and Smaling 1990; Rego *et al.* 2007, Sahrawat *et. al.* 2007). Soil degradation, through nutrient depletion and loss of organic matter, causes serious yield decline closely related to water determinants, as it affects water availability for crops, due to poor rainfall infiltration and plant water uptake, due to weak roots. It is estimated that approximately 85 per cent of African farmland in 2002-04 experienced a loss of more than 30 kg ha^{-1} of nutrients per year (IFDC, 2006).

A substantial increase in crop yields was experienced after micronutrient amendments in farmers participatory trials (in more than 300 villages) and a further increase by 70 to 120 per cent when both micronutrients and adequate nitrogen and phosphorus were applied, for a number of rain-fed crops (maize, sorghum, moong bean, pigeonpea, chickpea, castor and groundnut) in farmers' fields. Rainwater productivity (i.e. total amount of grains produced per unit of rainfall) was significantly increased in example above as a result of micronutrient amendment. The rainwater productivity for grain, production has increased by 70-100 per cent for maize, groundnut, moong bean, castor and sorghum by adding boron, zinc and sulphur. In terms of net economic returns, rainwater productivity was substantially higher by 1.50 to 1.75 times. Similarly, rainwater productivity increased significantly when adopting integrated land and water management options as well as use of improved cultivars in semiarid regions of India (Wani *et al.* 2003b).

Multiple Benefits and Impacts through Integrated Watershed Management

Through the use of new tools [i.e. remote sensing, geographic information systems (GIS) and simulation modelling] along with an understanding of the entire food production-utilization system (i.e. food quality and market) and genuine involvement of stakeholders, ICRISAT-led watersheds made remarkable impacts on SAT resource-poor farm households.

Reducing rural poverty in the watershed communities is evident from the transformation of their economies. The ICRISAT model ensured improved productivity with the adoption of cost-efficient water harvesting structures (WHS) as an entry point, for improving livelihoods. Crop intensification and diversification with high-value crops is one leading example that allowed households to achieve production of basic staples and surplus for modest incomes. The model has provision for improving the capacity of farm households through training and networking for improving livelihood through enhanced participation especially of the most vulnerable groups like women and the landless.

Building on social capital made a large difference in addressing rural poverty of watershed communities. This is evident in the case of Adarsha Watershed, Kothapally in Andhra Pradesh, India. Today, it is a prosperous village on the path of long-term sustainability and has become a beacon for science-led rural development. In 2001, the average village income from agriculture, livestock and non-farming sources was US$ 945 compared with the neighbouring non-watershed village income of US$ 613. The villagers proudly professed: "We did not face any difficulty for water even during the drought year of 2002. When surrounding villages had no drinking water, our wells had sufficient water." To date, the village prides itself with households owning five tractors, seven trucks and 30 auto-rickshaws. People from surrounding villages come to Kothapally for on-farm employment. Similarly, in Tad Fa and Wang Chai watersheds in Thailand, there was a 45 per cent increase in farm income within three years. Farmers earned an average net income of US$ 1195 per cropping season.

Crop livestock integration is another facet harnessed for poverty reduction. The Lucheba watershed, Guizhou province of southern China has transformed its economy through modest injection of capital-allied contributions of labour and finance, to create basic infrastructures like access to roads and drinking water supply. With technical support from the consortium, the farming system was intensified from rice and rape seed to tending livestock (pig raising) and growing horticultural crops (fruit trees like Ziziphus; vegetables like beans, peas and sweet potato) and groundnuts. In forage production, wild buckwheat was specifically important as an alley crop as it was a good forage grass for pigs. This cropping technology was also effective in controlling erosion and increasing farm income in sloping lands. This holds true in many watersheds of India where the improvement in fodder production has intensified livestock activities like breed improvement (artificial insemination and natural means) and livestock centre/health camp establishment (Wani *et al.* 2006).

Increasing crop productivity is a common objective in all the watershed programmes; and the enhanced crop productivity is achieved after the implementation of soil and water conservation practices along with appropriate crop and nutrient management. For example, the implementation of improved crop management technology in the benchmark watersheds of Andhra Pradesh increased the maize yield by 2.5 times (Table 5) and sorghum yield by threefold. Overall, in the 65 community watersheds (each measuring approximately 500 ha), implementing best-bet practices resulted in significant yield advantages in sorghum (35-270 per cent), maize (30-174 per cent), pearl millet (72-242 per cent), groundnut (28-179 per cent), sole pigeonpea (97-204 per cent) and intercropped pigeonpea (40-110 per cent). In Thanh Ha watershed of Vietnam, yields of soybean, groundnut and moong bean increased by threefold to fourfold (2.8-3.5 t ha^{-1}) as compared with baseline yields (0.5 to 1.0 t ha^{-1}), reducing the yield gap between potential farmers' yields. A reduction in nitrogen fertilizer (90-120 kg urea per ha) by 38 per cent increased maize yield by 18 per cent. In Tad Fa watershed of northeastern Thailand, maize yield increased by 27-34 per cent with improved crop management (Sreedevi and Wani, 2009).

TABLE 5—CROP YIELDS IN ADARSHA WATERSHED KOTHAPALLY DURING 1999-2007

Crop	1998	Yield (kg ha^{-1})									
	base-line yield	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006	2006-2007	Average yields	SE±
Sole maize	1500	3250	3750	3300	3480	3920	3420	3920	3635	3640	283.3
Improved Inter cropped maize		2700	2790	2800	3083	3129	2950	3360	3180	3030	263.0
Traditional inter-cropped maize		700	1600	1600	1800	1950	2025	2275	2150	1785	115.6
Improved inter-cropped pigeonpea		640	940	800	720	950	680	925	970	860	120.3
Traditional inter-cropped pigeonpea	190	200	180	-	-	-	-	-	-	190	-
Improved Sole Sorghum	-	3050	3170	2600	2425	2290	2325	2250	2085	2530	164.0
Traditional Sole Sorghum	1070	1070	1010	940	910	952	1025	1083	995	1000	120.7
Intercropped Sorghum	-	1770	1940	2200	-	2110	1980	1960	1850	1970	206.0

Improving water availability in the watersheds was attributed to an efficient management of rainwater and *in-situ* conservation, establishment of WHS and improved groundwater levels. In the various watersheds of India like Lalatora (in Madhya Pradesh), treated area registered a groundwater level rise by 7.3 m. At Bundi, Rajasthan, the average rise was 5.7 m and the irrigated area increased from 207 ha to 343 ha. In Kothapally watershed in Andhra Pradesh, the groundwater level rise was 4.2 m in open wells. The various WHS resulted in an additional groundwater recharge per year of approximately 4,28,000 m^3 on the average. With this improvement in groundwater availability, the supply of clean drinking water was guaranteed. In Lucheba watershed in China, a drinking water project, which constitutes a water storage tank and pipelines to farm households, was a joint effort of the community and the watershed project. This solved the drinking water problem for 62 households and more than 300 livestock. Earlier every farmer's household used to spend 2-3 hours per day in fetching drinking water. This was the main motivation behind the excellent farmers' participation in the project. On the other hand, in Thanh Ha watershed in Vietnam, collective pumping out of well water established efficient water distribution system and enabled farmers' group to earn more income by growing watermelon with reduced drudgery as women had to carry water on the head from a long distance (*Wani et al.* 2006).

Supplemental irrigation one of the climate change adaptation strategy can play a very important role in reducing the risk of crop failures due to and in optimizing the productivity in the SAT. In these regions, there is good potential for delivering excess rainwater to storage structures or groundwater because even under improved systems, there is loss of 12-30 per cent of the rainfall as runoff. Striking results were recorded from supplemental irrigation on crop yields in ICRISAT benchmark watersheds in Madhya Pradesh. On-farm studies made during 2000-03 postrainy seasons, showed that chickpea yield (1.25 t ha-^{1}) increased by 127 per cent over the control yield (0.55 t ha-^{1}); and groundnut pod yield (1.3 t ha-^{1}) increased by 59 per cent over the control yield (0.82 t ha-^{1}) by application of two supplemental irrigations of 40 mm. Similar yield responses in moong bean and chickpea crops were obtained from supplemental irrigation at the ICRISAT center in Patancheru (Pathak *et al.* 2009).

Sustaining development and protecting the environment are the two-pronged achievements of the watersheds. The effectiveness of improved watershed technologies was evident in reducing runoff volume, peak runoff rate and soil loss and improving groundwater recharge. This is particularly significant in Tad Fa watershed where interventions such as contour cultivation at mid-slopes, vegetative bunds planted with *Vetiver*, fruit trees grown on steep slopes and relay cropping with rice bean reduced seasonal runoff to less than half (194 mm) and soil loss less than 1/7th (4.21 t ha-^{1}) as compared to the conventional system (473 mm runoff and soil loss 31.2 t ha-^{1}). This holds true with peak runoff rate where the reduction is approximately one-third.

Introduction of IPM in cotton and pigeonpea substantially reduced the number of chemical insecticidal sprays in Kothapally, India during the season and thus reduced the pollution of water bodies with harmful chemicals. Introduction of integrated pest management (IPM) and improved cropping systems decreased the use of pesticides worth US$ 44 to 66 per ha (Ranga Rao *et al.* 2007). Crop rotation using legumes in Wang Chai watershed (Thailand) substantially reduced nitrogen requirement for rain-fed sugarcane. The IPM practices, which brought into use local knowledge using insect traps of molasses, light traps and tobacco waste, led to extensive vegetable production in Xiaoxingcun (China) and Wang Chai (Thailand) watersheds.

In climate change adaptation aspects, ICRISAT already has on hand climate ready 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 disease resistant varieties for *e.g.* in chickpea ICCV 96029 (super early 75-80 days), ICCV 2 (extra early 85-90 days) and KAK 2 (early 90-95 days). Using early maturing varieties, P fertilizer at planting for late onset of monsoon; high tillering cultivars and optimal root traits for mid-season drought; delay sowing, P fertilizer, water harvesting and run off control for early drought; early maturing traits for terminal drought; heat tolerance traits, crop residue management and large number of seedling per planting hill for increased temperature; better soil nutrient management to promote positive effect of increased CO_2 level are few ICRISAT strategies to over come the climate change as well variability on rain-fed production (Cooper *et al.* 2009).

Climate Change Mitigation

Agriculture sector in India contribute 28 per cent of the total green house gas (GHG) emissions (NATCOM, 2004) against the global average from agricultural sector is only 13.5 per cent (IPCC 2007 a). The gross emission of GHG from Indian agriculture is likely to increase significantly in future due to our need to increase food production. There are several potential approaches such as appropriate crop management practices, improved management of livestock diet and increase the soil carbon through carbon sequestration to reduce the GHGs emission from agriculture (Wani *et al.* 2003a, Aggarwal, 2008). The improved practices such as crop rotation with legumes, minimum tillage, crop residue addition and better soil and water management could help to more carbon sequestration of soil (Wani *et al.* 2003a, ICRISAT 2005). The carbon sink capacity of the world's agricultural and degraded soils is 50 to 66 per cent of the historic carbon loss of 42 to 78 giga tons of carbon (Lal, 2004). The rate of soil organic carbon sequestration with adoption of recommended technologies depends on soil texture and structure, rainfall, temperature, farming system and soil management. Strategies to increase the soil carbon pool include soil restoration and woodland regeneration, no-till farming, cover crops, nutrient management, manuring and sludge application, improved grazing, water conservation and harvesting, efficient irrigation, agroforestry practices and growing energy crops on spare lands. An increase of one ton of soil carbon pool of degraded cropland soils may increase crop yield by 20 to 40 kg ha-^{1} for wheat, 10 to 20 kg ha-^{1} for maize and 0.5 to 1 kg ha-^{1} for cowpeas. As well as enhancing food security, carbon sequestration has the potential to offset fossil fuel emissions by 0.4 to 1.2 giga tons of carbon per year or 5 to 15 per cent of the global fossil-fuel emissions (Lal, 2004). From the research conducted by ICRISAT on carbon sequestration, it was concluded that the inclusion of legumes in cropping system has increased soil N through biologically fixed N and also improved the ability of the Vertisol to sequester more carbon from atmosphere. A positive relationship between soil available P and soil organic C suggested that application of P to Vertisol increased carbon sequestration. Increased C sequestration at 7.4 t C ha-^{1} in turn increased the productivity of the legume-based system, thus ultimately enhanced soil quality. This study gives strong evidence that SAT soils, which has high potential to sequester more carbon through improved soil and water management practices to benefit the agricultural productivity and sustainability (Wani *et al.*, 2003a).

Evidence from On-station Field Experiments

Results from a long-term experiment on Vertisols at the ICRISAT farm in Patancheru, Andhra Pradesh, India, initiated in 1976, have conclusively shown that an improved catchment management/ production system that combines improved soil and water conservation practices (broad bed and furrows), improved legume-based crop rotations and improved nutrient management gave a five-fold yield increase (5.1 t ha^{-1} yr^{-1}) compared to the traditional system that yielded an average of 1 t ha^{-1} yr^{1} (Fig. 6). The improved system has a higher carrying capacity (21 persons ha^{-1}) than the traditional system (4.6 persons ha^{-1}). More importantly, under the improved catchment management system, the soil contains 46.8 t C ha $^{-1}$ in the 0-120 cm soil profile compared to the traditional management that contained 39.5 t C ha^{-1}. This is equivalent to a gain of 0.3 t C ha^{-1} yr^{1} (Wani et al. 2003a).

Evidence from Farmers' Fields

The C status of soils at the 28 benchmark sites, covering arid, semi-arid and moist humid tropical locations in India was determined to identify C sequestering systems. Total SOC, soil inorganic C (SIC) and total C (TC) stocks were estimated as 0.47, 0.71 and 1.8 pg for the black soils and 0.33, 0.50 and 0.83 Pg for the red soils, respectively; these soils cover nearly 15 million ha area in the SAT India. It was noted that the soils revisited after 25-30 years indicated an overall increasing trend in SOC. The threshold minimum and maximum values of SOC and bulk density for the 22 systems determined, comprising two forest-based, one fallow, two horticultural and 17 agricultural-based systems, identified as viable under the present level of management. The minimum and maximum threshold limits of SOC for the selection of viable systems were found to be 0.63 and 2.42 per cent, respectively, which corresponded to maximum and minimum bulk density values of 1.60 and 1.22 g/ cc, respectively. The Study showed that overall Vertisols had higher C sequestering potential than the Alfisols, the legume-based cropping systems with high management sequestered more C than the cereals, the horticultural systems (fruit) systems and grasslands sequestered more C than annual crop systems (Bhattacharyya et al. 2006).

The level of management adopted for the shrink-swell black soils during the last 25-30 years helped these soils to reach a higher quasi-equilibrium value (QEV) of SOC. These results indicate that these black soils or Vertisols respond to a management level and are not depleted in SOC. Also, the higher QEV of SOC (2.4 per cent) observed in forest soils indicates the potential of these soils under agricultural systems to further increase the QEV (Bhattacharyya et al. 2006). Recent studies on the sequestration of C especially in soils of the drier areas also points to the role of SIC (pedogenic carbonate) in capturing storing atmospheric carbon dioxide and enhancing SOC appears promising to enrich the soils of the drier regions with SOC (Sahrawat 2003; Bhattacharyya *et al.* 2008). Bhattacharyya *et al.* (2008) used soil carbon storage capacity as a criterion to prioritize areas for C sequestration in various agro-climatic zones of India. Thematic maps on soil C stocks were prepared for different regions and these maps are useful for planning purposes to prioritize C sequestration program in the country.

Furthermore, the results of the study showed that soil under irrigated rice double cropping had higher concentrations of SOC and N than sites under a rice-upland sequence or other cropping systems with or without legumes. Among the upland systems, the inclusion of legumes in rotation or as an intercrop positively influenced the concentration of SOC (Sahrawat et al. 2005).

By adopting bio-fuel-switch for carbon, women SHGs in Powerguda (a remote village of Andhra Pradesh, India) have pioneered the sale of carbon units (147 t CO_2 C) to the World Bank from their 4,500 Pongamia trees, seeds of which are collected for producing saplings for distribution/ promotion of biodiesel plantation. Normalized difference vegetation index (NDVI) estimation from the satellite images showed that within four years, vegetation cover could increase by 35 per cent in Kothapally. The IGNRM options in the watersheds reduced loss of NO_3-N in runoff water (8 vs. 14 kg. nitrogen per ha). Reduced runoff and erosion reduced risk of downstream flooding and siltation of water bodies that directly improved environmental quality in the watersheds (Pathak *et al.* 2005; Sahrawat *et al.*, 2005; Wani *et al.* 2005).

Bio-diversity Conservation

Conserving biodiversity in the watersheds was engendered through participatory NRM. The index of surface percentage of crops (ISPC), crop agro-biodiversity factor (CAF) and surface variability of main crops changed as a result of integrated watershed management interventions. Pronounced agro-biodiversity impacts were observed in Kothapally watershed where farmers now grow 22 crops in a season with a remarkable shift in cropping pattern from cotton (200 ha in 1998 to 100 ha in 2002) to a maize/ pigeonpea intercrop system (40 ha in 1998 to 180 ha in 2002), thereby changing the CAF from 0.41 in 1998 to 0.73 in 2002. In Thanh Ha, Vietnam the CAF changed from 0.25 in 1998 to 0.6 in 2002 with the introduction of legumes (Wani et al. 2005, Shiferaw et al. 2006).

Institution and Enabling Policies

Tangible economic benefits for the farmers through introduction of improved interventions cannot be achieved by working in disciplinary mode that is compartmental. The era of ultra-specialization and compartmental approach has bypassed and scientists need to work in multidisciplinary teams to address the complex issues faced on the farmers' fields. It is known that only application of nitrogen and phosphorus cannot guarantee the crop responses if the soils are deficient in zinc and other micro- or secondary- nutrients. Similarly, improved nutrient management options alone can not give the best results in the absence of suitable pest management options as well as suitable cultivars along with soil and water management interventions and market support.

Adopt integrated water resource management approach in the watersheds by discarding the artificial divide between rain-fed and irrigated agriculture. There is an urgent need to have sustainable water (rain-, ground- and surface-water) use policies to ensure sustainable development. As described earlier in the absence of suitable policies and mechanisms for sustainable use of groundwater resources benefits of watershed programs can easily be undone in short period with over exploitation of the augmented water resources. Cultivation of water inefficient crops like rice, sugarcane need to be controlled using groundwater in watersheds through suitable incentive mechanisms for rain-fed irrigated crops and policy to stop cultivation of high water requiring crops.

Innovative institutional mechanisms such as Consortium approach for technical backstopping (Wani et *al*; 2003a), empowerment of community-based organizations (Wani et al; 2003a, 2006), strengthening of area groups as is the case in Sujala Watershed program, strengthening of SHGs in APRLP, women's village organization (VO) in APRLP or Village organization like in Sujala watershed program in Karnataka as PIAs, including Gram Panchayat representatives in Watershed Committee (governing body), concurrent monitoring and evaluation by an independent body as evaluated in Sujala Watershed program, participatory M&E involving community and other stakeholders, transparency at village level, farm-based planning (net planning) (Indo German Program), trained farmers as master trainers are found effective institutional mechanisms. There is an urgent need to identify such effective institutional mechanisms for enhancing the impact and sustainability of watershed programs (Wani *et al.* 2008ab).

Convergence of actors and their actions at watershed level to harness the synergies and to maximize the benefits through efficient and sustainable use of natural resources to benefit small and marginal farmers through increased productivity per unit of resource. We have missed out large benefits of watershed programs due to compartmental approach and there is an urgent need to bring in convergence as the benefits are many folds and its win-win for all the stakeholders including number of line departments involved in improving rural livelihoods.

New institutional mechanisms are also needed at district, state and national level to converge various watershed programs implemented by number of ministries and development agencies to enhance the impact and efficiency by overcoming duplicity and confusion. In 2005, the National Commission on Farmers recommended a holistic integrated watershed management approach, with focus on rainwater harvesting and improving soil health for sustainable development of drought prone rain-fed areas (Government of India, 2005). Recently, Government of India has established National Rain-fed Area Authority for Sustainable Development of Rain-fed Areas (NRAA) with the mandate to converge various programmes for integrated development of rain-fed agriculture in the country Recently GoI has released new common watershed guidelines (GoI, 2008) recommending decentralization of authority to the state, refocusing, the objectives for improving livelihoods and sustainable development, promoting consortium approach, capacity-building thru quality service providers addressing issues of gender and equity through specific financial allocations for livelihood generating options, use of new science tools for planning, monitoring and evaluation of watersheds and participatory approach through village level institutions (GoI. 2008). These are welcome developments, however, it is just a beginning and lot more still need to be done to provide institutional and policy support for development of rain-fed areas. Thus, it has become increasingly clear that water management for rain-fed agriculture requires a landscape perspective and involves cross-scale interactions from farm household scale to watershed/ catchment scale.

Capacity-Building

Knowledge management and sharing is an important aspect in management of NRs for sustainable development. Use of new information and communication technologies (ICTs) to cover the last mile to reach the un-reached is must as existing extension mechanisms are not able to meet the ever growing demand as well as to share the new and vast body of knowledge with large number of small and marginal farmers. Innovative methods and new local community members need to be empowered as extension agents by linking them with knowledge resource centers.

Align M&E processes as per the objectives and use quantitative and qualitative indicators judiciously for assessing the effectiveness of the programs as well as for doing the mid-course corrections in the strategy. Select suitable impact assessment methods at different levels and use new science (social as well as biophysical) tools to assess the impact collecting quality data selectively rather than collecting voluminous reports out of the mill approach.

Watersheds to be developed as business model through public-private partnership (PPP) using principles of market-led diversification using high-value crops, value chain approach and livelihood approach rather than only soil and water conservation approach. Strengths of rain-fed areas using available water resources efficiently through involvement of private entrepreneurs and value addition can be harnessed by linking small and marginal farmers to markets through PPP business model for watershed management (Wani *et al.* 2008).

Conclusions

With its long experience, investments, development of technical human power and access to new technologies such as remote sensing India has a potential to be a global leader in the area of development of rain-fed agriculture through integrated watershed management to reduce the impact of climate change. There is an urgent need to make quick adjustments in our approaches by adopting new paradigm for development of rain-fed areas and necessary investments must be made to ensure inclusive growth and increase the food production and ensuring the rain-fed sustainability. It will be a role model not only for India it self but also for all the developing countries in Asia and Africa. These countries are plagued with the same dilemma of achieving inclusive sustainable growth including small and marginal farmers from rain-fed areas, to achieve food security and overcome the looming water scarcity, increasing temperature, rainfall variability (intensity and pattern) and CO_2 enrichment. The challenge faced in the country can be converted in to an opportunity and harnessed through urgent steps and increased investments in development of rain-fed agriculture.

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