



Sustaining Crop Production in Rainfed Areas in India: Issues and Strategies

Raj Singh^{1*}, Anchal Dass¹ and V. K. Singh¹

¹Division of Agronomy, ICAR-IARI, New Delhi, 110012, India.

Authors' contributions

This work was carried out in collaboration among all authors. Author RS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors AD and VKS managed the analyses of the study. Author VKS managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The Agriculture sector plays an important role in the Indian Economy. Besides assuring the food grain security to nearly 1350 million (m) human population and fodder security to 512.05 m livestock population of the country, it contributes about 16% of total GDP, 12.5% of total export, and provides employment to over 50% total workforce of the country. Owing to the introduction of improved production technologies, expansion of irrigation facilities, increase the use of synthetic inputs, popularization of the technologies, implementation of policies for the agricultural development and greater investment in agricultural sector, food grain output in the country increased from 51.8 million tons (m.t) in 1950-51 to 285.01 m t in 2018-19. The growth rate of food grain production for the period between 2010-11 and 2017-18 was almost double the population growth rate. Despite the overwhelming growth in food grain production, market size, availability of improved production technologies and being the front ranking producer of many crops in the world, Indian agriculture is still facing several challenges, which are severely affecting its performance, income, employment and livelihood of the farmers. Rainfed agriculture in India occupies the largest area and the value of the produce in the world. It accounts for nearly 52% of the total net cultivated area of the country. Rainfed agriculture must play an important role in food security and sustainability of livelihoods because

*Corresponding author: E-mail: rajsingh221996@gmail.com;

almost 40% human and 60% livestock population of the country depend on it. But, it is And characterized by unstable yield, dominance of marginal and small operational holdings, occurrence of frequent drought, low income, and lack of regular employment, food insecurity, out migration, malnutrition and poor socio-economic status of the inhabitants of the rainfed regions. In the era of globalization, transformation of subsistence agriculture to commercial agriculture coupled with increase of income higher per unit area is the need of the day to sustain the people's livelihood in the rainfed regions. Efficient use of rainwater and soil moisture, adoption of improved production technologies of crop production, alternate land use systems (ALUS), integrated farming systems (IFSs), conservation of natural resources and better access to markets are of prime importance not only for enhancing crop production, income and employment, but also to sustain the livelihoods of the farmers under variable climatic condition of the rainfed regions. Hence, efforts have been made to discuss the constraints and improved production technologies, which can be effective to realize higher crop productivity and income from the rainfed agriculture in India.

Keywords: Rainfed; agriculture; livelihood; climate; livestock population.

1. INTRODUCTION

Agriculture plays an important role in strengthening the country's economy, food, and nutritional security. Over the last five decades, Indian agriculture has made tremendous progress; the country has not only achieved self-sufficiency in food grains but also earning foreign exchange by exporting food grains. The production of food grains in India was only 50.8 m t in 1950-51 and 82.02 m t in 1960-61 (Table 1), which was not enough to feed 361.1 and 438.2 million mouths during respective years. Due to the use of improved production technologies during the green revolution period, food grain production increased up to 284.8 m t in 2017-18 [2]. The share of agriculture in the national Gross Domestic Product (GDP) is about 16% and in the total export of the country 12.5%. Moreover, agriculture employs about 50% of the total workforce of the country. World's 18% of human and 15% of livestock population live in India with only 4.2% of fresh water resources and 2.3% of the geographical area of the world (Rao et al., 2015). Therefore, enormous pressure to produce more food from less land with shrinking natural resources to feed its rapidly increasing population is a major concern before the policymakers, scientists, and administrators of the country. The population of the country is increasing steadily and expected to reach 1.65 billion by 2050, and will require around 400 million tons of food grains to provide food [68]. To keep up the momentum of growth in agricultural production, there is a need of exploiting the available resources at maximum level in the sustainable manner. But it is not so easy task as agriculture too has its own set of challenges, some of which are very critical and impeding.

1.1 Major Challenges

- Land is being continuously fragmented due to rapidly increasing population and inheritance law. As a result, size of operational holdings declined up to 1.08 ha in 2015-16 compared to 2.28 ha in 1970-71 (Agriculture Census, 2015-16). In addition, the per capita land availability is gradually decreasing. The per capita land availability declined from 0.91 ha in 1951 to 0.32 ha in 2001, which further estimated to decline to 0.19 ha in 2050 [37]. The small and marginal holdings constituted 86.21% in 2015-16, which are not able to afford expensive resources, technologies, and commercial agriculture. The lesser land holdings directly affect the agricultural productivity, production, and income of the farmers.
- The possibility of increasing the area under cultivation is very limited as land use is increasing for non-agricultural activities. The net sown area was 140.96 million hectares in 1970-71, while in 2014-15 it was also 140.13 million hectares (Table 1).
- Land degradation is one of the major issues, which is due to many forces, which include extreme weather conditions, additional use of fertilizers, insecticides, water, ploughing, deforestation and many other human activities. Nearly, 94 m ha land is suffering from water erosion, 16 m ha from acidity, 14 m ha from floods, 9 m ha from wind erosion, 6 m ha from salinity, and 7 m ha by combination of factors [5].

- Soil fertility is one of the most important factors to attain a desirable level of agricultural production, but imbalanced and inadequate amount of fertilizers coupled with over-exploitation of soil fertility have caused macro-and micro-nutrients deficiency in the soil. In India, about 59, 36 and 5% area are low, medium and high in available N, respectively. Similarly, soils of about 49, 45 and 6% area are low, medium and high in available P, respectively; and soils of around 9, 39 and 52% area are low, medium and high in available K, respectively (Chaudhari *et al.*, 2015). Furthermore, nearly 49, 15, 6, 8, 11 and 33% soils are suffering by zinc, iron, manganese, copper, molybdenum and boron deficiency, respectively [49]. The deficiencies of macro-and micro-nutrients have become major constraints to productivity, stability, and sustainability of soils.
- Increase in agricultural production mainly through increase in productivity is a key of assuring food security, poverty reduction, employment and income generation and sustaining livelihood. The combination of land, labour, capital and physical inputs is known as the total factors and the ratio of aggregation of output (total factor) is known as total factor productivity. The total factor productivity is continuously decreasing. A recession has started in Haryana and Punjab, but the total wheat productivity is still increasing in these two states [29]. In a study, Tripathi [63] sub-divided the period of from 1969-70 to 1979-80, 1980-81 to 1990- 91, and 1991-92 to 2005-06 in to three parts and found that contribution of total factors productivity was in negative at -0.11% during the entire period.
- Out of 141.4 m ha net cultivated area, only 68 m ha is covered by irrigation facility, while remaining 74 m ha is rainfed, which is nearly 52% of total net cultivated area [21]. The average productivity of rainfed agriculture is very low (> 1 t/ha), as it is endowed with fragile and harsh agro-climatic conditions, dominated with harsh bio-physical and socio-economic environments. Agriculture is the largest user of water and it is projected that water requirement for irrigation purposes will increase up to 910 BCM by 2025 and 1072 BCM by 2050 [10]. On the other hand, water requirement for non-agricultural sectors like drinking, industry, energy and other purposes will increase simultaneously. Under such situation, providing the water for irrigation purposes will be a very difficult task.
- There are many other important barriers like climate change, increase in pest outbreaks, lack of biodiversity, poor mechanization, marketing problems, lack of proper credit facilities, poor access to improved technologies, and storage facilities, etc., which directly or indirectly affect the agricultural production. According to World Meteorological Department, the global surface temperature has increased by about 1.1°C

Table 1. Population growth, net cultivated area and food grain production

Year	Population (million)	Av. Annual exponential growth rate (%)	Net-cultivated area (m ha)	Food grain production (m t)
1950-51	361.1	1.25	118.75	50.82
1960-61	439.20	1.96	133.20	82.02
1970-71	548.2	2.20	140.27	108.42
1980-81	683.3	2.22	140.00	129.59
1990-91	846.4	2.16	143.00	176.32
2000-01	1028.7	1.97	141.34	196.81
2010-11	1210.9	1.50	141.56	244.49
2014-15	-	-	140.13	252.02
2016-17	-	-	-	275.11
2017-18	-	-	-	285.01
2018-19	-	-	-	-

Source: Agricultural Statistics [2]

over pre-industrial era (1850–1900). In India, during the year of 1901–2018, the average annual temperature has been rising in every 100 years by 0.6 °C (IMD, 2019). Rising temperature and change in the rainfall pattern can reduce the GDP of India up to 2.8% by 2050 [69] and can suppress the quality of life for almost half of the country's population. Further, it is estimated that climate change could reduce average farm income by 15-18% and 20-25% in rainfed condition (Mahapatra, 2018). Apart from this, more than 50 million people in India will be affected by sea level rise and related coastal floods.

All the above challenges affecting the growth rate of agricultural production and continuous increase of food grain demand will compel to increase food grain production per unit area from the shrinking resources. To maintain the pace of growth of food grain production, the strategy of agricultural production has to be changed. Conventional farming will need to be converted into modern and sustainable farming. Apart from this, it would be necessary to pay more attention on rainfed agriculture, as it accounts for a significant share in total food grain production and will have to play an important role in future to meet the food grain requirement of the country. Therefore, increase of average yield of rainfed agriculture is of prime importance to assure food grain security in the country. But, there is a need for a holistic approach to utilize the scarce natural resources in a sustainable manner to enable the rainfed agriculture to be more productive under adverse agro-climatic conditions and be emerge as a major opportunity in raising overall agricultural growth. Therefore, considering the problems related to the rainfed agriculture, a proper action plan is needed to redress them, to make it more productive and sustainable in the country.

2. RAINFED AGRICULTURE

Rainfed agriculture is the most important component of global agriculture for maintaining global food security and is likely to remain a major component of the global food system, as it has to play a crucial and dominant role in providing food and livelihood security for the rapidly growing population. Rainfed agriculture occupies about 1.22 billion-hectare (B ha) area worldwide, which is about 82% of total area (1.5 B ha) under agriculture [48] and contributes

nearly 58% to the global food basket. It is practiced under a wide variety of agro-climatic, edaphic and socio-economic conditions and globally, rainfed agriculture accounts for more than 95% of farmed land in sub-Saharan Africa, 90% in Latin America, 75% in the Near East and North Africa; 65% in East Asia and 60% in South Asia [23]. Complex climatic deficiencies, variable rainfall pattern, high temperature, high potential evapo- transpiration and poor physical, chemical and biological properties of the soil make rainfed agriculture highly vulnerable to frequent drought and famine. As a result, the livelihood of the major proportion of the global population is unstable. The largest part of the poor world population lives in the least developed countries, where agriculture is practiced under uncontrolled conditions and solely dependent on the occurrence and distribution of rainfall. Besides low agricultural production, many new driving forces like income growth, globalization, urbanization, and climate change are also playing greater role in influencing livelihood of inhabitants in rainfed areas [65]. Although due to the development of modern agricultural technologies, there has been a lot of progress in the rainfed agricultural production but owing to low adoption of modern technologies, it is not enough to meet the food grain demand for the rapidly growing population. According to UNO (2017) report, a number of hungry people are rising rapidly and 11% of the global population suffered from hunger in 2016. Asia region has the largest number of hungry people (63.8%) in the world followed by 29.82% in Africa and 5.15% in Latin America and the Caribbean regions in 2016. The world population is increasing at an alarming rate and it is expected that global population will increase up to 8.6 billion (B) in 2030, 9.8 B in 2050 and 11.2 B in 2100 [64]. The ever expansion of the population is causing pressure on the finite resources, as a result shrinking of land and water for food grain production and there will be a little possibility for the horizontal expansion of the area to increase food grain production. The impact of climate change on agriculture could result in problems with food security and may threaten the livelihood activities upon which much of the population depends [45]. Therefore, it is of prime importance to increase the food grain production per unit area through the adoption of modern agricultural production technologies.

In India, rainfed agriculture is a pre-dominating production system and has great contribution to the total food grain production of the country.

India ranks first in the world in terms of area (74 m ha) under rainfed agriculture and value of the produce. Rainfed agriculture is practiced in about 52% of total net cultivated area (140.0 m ha), which is widely distributed in different agro-climatic zones of the country and contributes nearly 44% to the total food grain production of the country. Though country has made tremendous progress in the expansion of irrigated area during last six decades and net irrigated area has increased over three times since 1950-51 (Table 2), still area under rainfed agriculture is over stepping the irrigated area and even after exploiting all the irrigation potentialities of the country nearly 40% area will remain under rainfed agriculture. Therefore, rainfed agriculture has an important role in maintaining food security in the country and it will remain so in the future also. Rainfed agriculture is occupying nearly 85% of coarse cereals, 83% of pulses, 70% of oilseeds, 42% of rice and nearly 65% of cotton area of the total acreage under these crops in the country [44]. A detail of the share of different crops grown under rainfed condition is given in Table 3. However, average yields of rainfed crops are less than a t/ha, as low input-low risk-low yield concept dominates in the rainfed

regions. Further, rainfed areas are endowed with a fragile and harsh bio- physical and socio-economic environment, resulting in partial or complete crop failure due to the occurrence of frequent droughts. As a result, rainfed areas are characterized with largest concentration of poverty and backwardness in the country. To overcome the challenges of low production and poor socio-economic status of the inhabitants of rainfed areas, specific actions from the policy makers, administrators, scientists and extension personnel are required to maximize and stabilize the agricultural production through the adoption of improved technologies related to efficient management of scarce and natural resources, increasing agricultural production and resilient to climate change to harness existing untapped potential of rainfed agriculture. Upgradation of rain-fed agriculture through sustainable use of natural resources promises large social, economic and environmental paybacks, particularly in poverty reduction and economic development. Moreover, poverty ratio, land and labour productivity, consumption of food grains and social development in rainfed agriculture are lower than irrigated areas (Table 3).

Table 2. Net and gross irrigated area pattern in India

Year	Net irrigated area (m ha)	Gross irrigated area (m ha)
1950-51	20.90	22.60
1960-61	24.70	28.00
1970-71	31.10	38.20
1980-81	38.70	49.80
1990-91	48.02	63.20
2000-01	55.20	76.19
2010-11	63.66	88.93
2011-12	65.70	91.78
2012-13	66.27	92.25
2013-14	68.10	95.77
2014-15	68.40	-

Source: Agricultural statistics [1], ministry of agriculture, cooperation and farmers welfare

Table 3. Comparison of important characteristics of predominantly rainfed and irrigated regions of India

Parameters	Rainfed regions	Irrigated regions	All Regions
Poverty ratio, head count, %	37	33	35
Land productivity, INR/ha	5716	8017	6867
Labour productivity, INR/ha	6842	9830	8336
Per capita consumption of food grains, kg/year	260	471	365
Infrastructure development index	0.30	0.40	0.35
Social development index	0.43	0.44	0.43

Source: Sharma et al. [47]

2.1 Classification of Rainfed Agriculture

Considering the rainfall occurrence, rainfed agriculture can be classified into the following groups.

2.1.1 Arid farming

Cultivation of crops in areas which receive annual rainfall less than 300 mm is called arid farming. It is

mostly characterized with extreme moisture shortage, rainfall variability, high temperature, high potential evapo-transpiration rate, poor soil structure and soil fertility, highly degradation of natural resources and recurrent drought. Mono-cropping systems dominate with limited crop choice. Besides some grasses, shrubs and trees, only few drought hardy arable cereal, pulses and oilseed crops are grown at the occurrence of rainfall. Partial or complete crop failure is a regular phenomenon and sustainable livelihood is the major concern in the region.

2.1.2 Dry farming

It is an improved system of cultivation in which maximum amount of moisture is conserved in low and untimely rainfall for the production of optimum quantities of the crop on an economic and sustainable basis. The purpose of dry farming is to conserve limited moisture by reducing or even eliminating runoff and evaporation, thereby increasing soil absorption and retention of moisture. Usually, dry farming receives annually a rainfall of 750 mm or less. Soil moisture conservation is one of the most important aspects of dry farming through different soil moisture conservation practices. More emphasis is given on the sustainable crop production rather than yield maximization. Some selected drought resistance crops and varieties are grown either as a sole, mixed or intercrops.

2.1.3 Dryland farming

The area which receives annual rainfall more than 750 mm and crops are grown following the improved soil and crop management practices with the use of rain water. Soils of the dry land areas are very deficient in nutrients and prone to erosion. Further, aberrant behavior of monsoon rainfall results in frequent droughts that impact resource poor farmers. Eroded and degraded soils with low water-holding capacity and multiple nutrient deficiencies, declining groundwater

table, etc. also contribute to low crop yields in dry land areas. These areas produce mainly pulses, sorghum, millet, groundnut and some oilseed crops and play a dominant role in agricultural production.

2.1.4 Rainfed farming

Cultivation of crops in regions where rainfall is more than 1150 mm. There are fewer chances of crop failures due to dry spells. However, adequate rainfall and drainage become an important problem in rainfed farming. This farming is practiced in humid regions. Broadly rainfall zone can be divided into five groups (Table 4).

Rainfed agriculture spanning several agro-ecologies in the country and it has a very important role to play in inclusive growth, food security, livelihoods, and sustainable development. The rainfed agriculture is practicing in arid, semi-arid, humid, semi-humid and per-humid conditions of the country. About 15 million ha land receive rainfall less than 500 mm, 15 mha 500–750 mm, 42 million ha 750 to 1150 mm and 25 m ha more than 1150 mm rainfall annually [59].

2.2 Constraints of Production in Rainfed Agriculture

Though irrigated agriculture plays a major role in producing 60% food grains from the 48% area, but due to several limitations, it is not possible to convert the whole cultivated area into the irrigated area. Therefore, rainfed agriculture will remain important, but the average productivity of rainfed areas is very low, which is less than one t/ha and tend to be relatively low compared to potentiality. Several

constraints are responsible for the low productivity of rainfed agriculture.

2.2.1 Climatic constraints

Climate is one of the most important determinants of agricultural production. Rainfed agriculture is characterized by its harsh and variable climatic condition, which is a major determinant of crop yields. Low and erratic rainfall, high temperature, High solar incidence, high wind velocity, low humidity, weather aberrations, drought, flood, frost, gale, cyclones and burning winds with high potential evapo-transpiration rate make the unfavorable condition

for the crop cultivation. Severe moisture stress can cause partial or complete crop failure. The growth of crops and the food production of the country are strongly influenced by the total rainfall. Rainfall aberrations during south-west monsoon continue to be a major factor contributing to instability in *kharif* crops production. The rainfall distribution is becoming more skewed with less number of rainy days, with high intensity causing more soil erosion. Besides rainfall variations, the distribution of rainfall is also changing in key rainfed agricultural locations and occurrence of the rainfall determines the sowing of the crops under rainfed condition. Distribution of rainfall is more important than total rainfall to have longer growing period in rainfed agriculture. Delay in the onset of monsoons severely affects the crop yield due to delay in the sowing of the crops. Further, loss of soil moisture and its duration of availability in the soil, crop growth and duration of the crop is directly governed by the temperature. It highly influences germination, growth and development, physical and chemical processes within the plants. Solar radiation governs all physical process taking place in the soil, plant and environment and controls distribution of temperature. Extremes events of rainfall, flood, heat and cold wave cause significant impact on the performance of crop growth and yields. Therefore, climate is the most important factor that significantly influences the growth and yield of crops in general and the rainfed condition in particular.

2.2.2 Edaphic constraints

Soils of the rainfed areas are pre-dominantly poor and marginal lands, which are inherently poor in soil organic matter. Singh et al. [58] reported 2.13 Pg carbon (C) stock in the 0-100 cm depth of which 1.23 Pg as soil organic C and 0.90 Pg as soil inorganic C in arid and semi-arid regions of Rajasthan. Major soils of the rainfed areas have been mapped in Alfisols (30%), Vertisols (35%), and Entisols (10%) [67]. All these soils have a wide diversity in texture, structure and organic matter status, and soil depth. Variations found in the different soils induce differences in infiltration rate, water holding capacity, bulk density, aggregation, aeration, permeability and moisture, and nutrient release capacity. Moreover, rainfed areas have uneven topography and poor quality of groundwater, which contains high soil pH, EC, and SAR. The abundance of sand makes the soil prone to erosion, as a result of low organic

matter content. Many soil factors like soil moisture, soil temperature, soil air, nutrients, and soil reactions significantly governed by the soil type those directly or indirectly affect the plant growth and yield.

2.2.3 Technological constraints

Adoption of modern agricultural technology by farmers is an important factor for improving the agricultural productivity in any kind of production systems. Limitations of adoption of improved production technologies and low adoption of technologies in the rainfed regions cause low crop production. Of course, inadequate awareness about the technologies, economic viability and lack of easy access to technology and credit also play vital role in the low adoption of technologies. Despite good progress made so far, the adoption and diffusion of key rainfed technologies are still low at national level, resulting in large yield gaps between research stations and farmer's fields [11]. In a study Singh et.al. [53] found that none of the farmers used recommended modern production technologies of barley and chickpea crop in arid region of Rajasthan, indicating 100% adoption gap. Adoption level of the improved production technologies needs to be increased for obtaining desirable yield level through the use of different extension methods in rainfed agriculture.

2.2.4 Socio-economic constraints

About 80% of farm holdings are managed by marginal and small categories of farmers. Majority of these category farmers are resource-poor coupled with poor socio-economic conditions. Owing to low risk-bearing capacity, low use of improved inputs (seed, fertilizer and pesticides), poor mechanization, low credit availability, low level of knowledge, lack of inspiration and initiation make it difficult to use the improved production technologies, consequently traditional farming is dominating in the rainfed condition. Low input -low risk -low yield concept is prevailing in the rainfed condition.

3. EFFICIENT MANAGEMENT OF RAINFED AGRICULTURE

Rainfed agriculture is being adversely affected by climatic, edaphic, technological and socio-economic problems, which together put a hard challenge to the development of sustainable livelihood for the inhabitants of these areas. The

challenges can be made least effective through narrowing the gap between the technology evolution and adoption. To bridge the yield gap, many national and international research organizations are working to develop technologies to improve productivity, profitability, risk reduction and livelihoods of people dependent on rainfed agriculture.

3.1 Water Management

Water is the most important and scarce resource for rainfed agriculture. The availability of water in the form of rainfall varies from 150 mm to more than 1500 mm/annum and most of it (about 80%) occurs in four months (June to September). Much of rainfall occurs as erratic with large variation in its intensity and time of occurrence. A major share of rainfall is lost through runoff, consequently causes soil erosion and moisture shortage. It is, therefore, necessary to store the runoff water for providing the moisture to the crop production in rainfed areas. Collection and storage of runoff water for the use of different agricultural activities, such as cultivation of different crops, grasses and trees, livestock production and domestic water supply purposes is called water harvesting. Its effective use can play a vital role for increasing agricultural production and sustainable livelihood in rainfed agriculture. Runoff water can be harvested by using different rainwater harvesting methods.

3.2 In-situ Rainwater Harvesting

Collection and storage of rainwater in the soil, where it is to be utilized is called in-situ rainwater harvesting. Loss of runoff water is prevented

through conservation in the soil profile and increasing the infiltration rate by prolonging the time. It is practiced in a variety of ways depending upon topography, soil, and rainfall. Runoff water is captured in the field by using various types of barriers. Many practices like tillage, field bunding, contour bunds, pitting, strip bunding, terracing, land leveling, inter-row or inter plot water harvesting, circular or semi-circular micro-catchments, vegetative barriers, etc. can be used as a barriers to check the runoff and soil moisture can be conserved in the field itself for the cultivation of different crops. In-situ water harvesting have been found to be very effective for increasing the yield in low rainfall condition. A study carried out at CAZRI, Jodhpur revealed that the yield of pearl millet was obtained almost 3 times with water harvesting compared to conventional practice in low rainfall condition and an increase of about 100% water use efficiency (WUE) was recorded in the study (Table 5). In-situ water harvesting also helps in efficient use of N-fertilizer in pearl millet (Table 6). Application of 40 kg N ha with in-situ water harvesting improved pearl millet grain yield by 27% with 69 mm of additional runoff compared to rainfed condition.

Deep tillage is one of the common practices that not only effective to provide a favorable environment for the proper germination and growth of the plants, but also help in increasing the soil moisture holding capacity through increased porosity, infiltration rates and reducing the surface runoff by providing barriers to the runoff water. A study carried out under semi-arid

Table 4. Classification of rainfall zones in India

Rainfall (mm)	Zone	Net Sown area (%)	Rainfall
<500	Arid	16	Very low
500-750	Semi-arid	17	Low
750-1100	Dry sub-humid	35	Medium
1100-1400	Moist sub-humid	24	High
>1400	Humid mountains	8	Very high

Source: Ramakrishna et al. [43]

Table 5. Water- use, yield and WUE of pearl millet under water harvesting

System	Good rainfall			Low rainfall		
	Water use (mm)	Yield (kg/ha)	WUE (kg/ha/mm)	Water-use (mm)	Yield (kg/ha)	WUE (kg/ha/mm)
Conventional practices	440	2320	5.3	143	400	2.9
In -situ water Harvesting	630	2425	3.9	212	1240	5.9

Source: Saxena et al. [46]

Table 6. Water- use, yield and WUE of pearl millet under water harvesting

System	Added water	N –levels /yield of pearl millet (kg/ha)	
		0	40
Rainfed	0	210	400
<i>In -situ</i> water harvesting	69	660	840

Source: Saxena et al. [46]

Table 7. Effect of deep ploughing on the yield of some dryland crops

Soil type	Crop	Yield t/ha)	
		Local plough	Deep plough
Alluvial	Maize	2.22	2.65
	Pearl millet	2.24	2.56
	Wheat	2.38	2.81
Red	Castor	4.00	6.00
	Groundnut	1.80	2.40
	Pigeon pea	5.90	7.60
Black Desertic	Castor	4.2	6.00
	Pearmillet	1.34	1.58
	Mung bean	0.47	0.58

Table 8. Effect of improvement in catchment area on runoff

Treatment	Average runoff of 4 years (mm)
Silvi-pasture	15.8
Silvi-culture	31.4
Cropped land	40.7
Control (Untreated)	106.5

Table 9. Effect of supplementary irrigation on grain yield (t/ha) of different crops

Stage of Irrigation	Chickpea	Linseed	Safflower
No irrigation	1.3	0.9	1.2
Pre-sowing (PS)	2.1	1.0	1.5
PS+flowering (F)	2.4	1.3	1.7
PS+pod filling	2.5	1.4	1.7
PS+F+pod filling	2.7	1.5	1.9
C.D. (5%)	0.13	0.04	0.12

conditions at Hyderabad by Kumar *et al.* [30] revealed that summer tillage helped in enhancing soil moisture retention by 20%, reduction of weed infestation by 40% and increased higher yields. Deep ploughing is also very effective to conserve higher moisture as compared to conventional ploughing. Oswal [39] found significant improvement in the yield of various *kharif* crops, such as pearl- millet, greengram, castor, etc. due to deep ploughing over conventional ploughing in different soils (Table 7). Laying out of ridge-furrow configuration against the prevailing wind erosion direction of the south-west to the north-west was found effective for increasing moisture availability in the arid region [51]. Vegetative barriers are very effective to check the runoff water losses. Khan *et al.*, (2009) reported that due to the

adoption of silvi-pasture system runoff was recorded 15.8 mm compared to 106.5 mm in untreated condition (Table 8). Dass *et al.* [16,17], Dass and Sudhishri [15], Dass *et al.*, [14] Sudhishri *et al.* [60,62], Lenka *et al.* [31-33] and Jakhar *et al.* [24,25] reported significant reductions in runoff, soil and nutrient losses, soil improvement and consequent crop/tree/ grass yield enhancements due to the use of bed planting, intercropping, vegetative barriers and agro-forestry systems

3.3 Ex-situ Rainwater Conservation

Water stored in reservoir or pond for recycling harvested runoff water is of utmost importance in for providing supplemental irrigation during the

moisture deficit period. Runoff water can be stored in several surface water harvesting structures like ponds, tanks, *khadins*, etc. Farm ponds hold a great promise as life-saving irrigation for rainfed crops. Runoff water is also harvested from shallow, gravely and rocky upland catchments in the low-lying valley plains that are converted into bunded farmland structure (*khadin*) where *kharif* and *rabi* crops are raised, depending upon the amount of rainfall and consequent runoff received during the monsoon. The *khadins* of Jaisalmer and Barmer district in Rajasthan are the best examples of this phenomenon. Khan and Singh [28] recorded the highest seed yield of chickpea (1803 kg/ha) grown in *Khadin* under conserved moisture conditions. Bhandarkar [7] reported that recycling of the runoff water at different stages significantly increased grain yield of chickpea, linseed, and safflower (Table 9).

3.4 Crop Management Practices

Crop management practices are one of the effective approaches to realize a higher yield due to the efficient use of water available in the soil profile. Much physical, chemical and biological impedance can be reduced due to the adoption of improved crop management practices. There are many crop management practices like selection of suitable crop and variety, weed management, nutrient management, suitable cropping system, intercropping system, crop rotation, use of mulches, residue incorporation, efficient method of supplemental irrigation, crop diversification, etc., those can play a vital role for increasing water use and yield through increasing rainwater use efficiency under rainfed condition.

4. SELECTION OF SUITABLE CROPS AND VARIETIES

Proper selection of suitable crops and varieties is an important factor for the success of crop production in rainfed agriculture. Crop growing period in arid, semi-arid and dry sub-humid condition varies between 60 and 270 days. Therefore, crop should be selected as per the period of moisture availability and consumptive use of the crops. The consumptive use of some pulse crops like moth bean, green gram, cowpea, and cluster bean is 218, 226, 280 and 332 mm, respectively. Rao *et al.* (1994) suggested crops and cropping pattern as per rainfall range and growing period for the arid region (Table 10).

Many crops and crop varieties have been found suitable for the different dryland and rainfed agriculture area of the country. Duration of the varieties is of paramount importance for dryland and rainfed agriculture. Priority should be given to the short duration varieties in the low rainfall areas. Many of the short-duration varieties like HHB 67, GHB 358, MPMH 17, Pusa composite 443 of pearl millet; SML 668, RMG 62, RMG 268 of green gram; GCH 5 and 7 of castor; JVR 497 and M 335 of groundnut; AKA 8 and BN bt. of cotton; SR 1904 and GJ 39 of sorghum, and HG 2 and 5 of horse gram have been recommended for dryland agriculture.

4.1 Intercropping

Intercropping is one of the ways to rehabilitate environment ecologically and it is more effective to obtain a higher yield than sole cropping because of many factors. Both intercrop and component crop benefit to each other due to their complementary effect [13,15]. Combination of a tall and dwarf crop as cereal and pulse/oilseed crop increase the water and nutrient-use efficiency compared to their sole cropping. A study carried out on the intercropping of pearl millet and moth bean by Singh Raj [52] revealed that intercropping of 2:1 row ratio of moth bean and pearl millet gave significantly higher yield and net returns over sole cropping of both the crops (Table 11).

4.2 Planting Time and Population

Due to the irregular behaviour of the rainfall, it is important that crop should be sown at the proper time to ensure proper germination and adequate plant population. Delay in the sowing may cause yield loss by creating moisture shortage at the grain formation stage because of early withdrawal of monsoon or terminal drought. Sowing at optimum time provide the opportunity to the crop to utilize optimum moisture by the roots under normal rainfall conditions. In addition, sowing crop with optimum seed rates at optimum spacing, plays an important role to maintain optimum plant populations and enable plants to use all growth factors efficiently.

4.3 Nutrient Management

Application of recommended dose of nutrients through suitable sources can have a significant effect on the moisture utilization and crop yield as well. A judicious use of nutrients increases the

Table 10. Cropping pattern as per growing period in arid zone

Rainfall range (mm)	Growing season (Weeks)	Cropping pattern
<150	<6	Only grasses and shrubs
150–250	6-8	Grasses (<i>Cenchrus ciliaris</i> , <i>Lasirus indicus</i>)
250–300	8-10	Short duration pulses (moth bean, green gram, cowpea, cluster bean)
300–400	10-12	Short-duration varieties of pearl millet and pulses

Table 11. Effect of intercropping system on the yield and economics

Treatments (Moth bean: Pearl millet)	Moth bean eq.seed yield (kg/ha)	Net return (Rs./ha)	WUE (kg seed/ha-mm)
2:1	567	18342	2.20
1:2	477	13919	1.73
3:1	555	17732	2.19
1:3	472	13679	1.68
2:2	509	15478	1.91
Pearl millet sole	429	11540	1.46
Moth bean sole	434	11665	1.77

Table 12. Effect of variety and nutrient management on the yield and WUE of chickpea

Treatment	Seed yield (kg/ha)	WUE (kg/ha-mm)
<i>Variety</i>		
Local	1433	6.02
RSG 44	1803	7.32
CD (P=0.05)	249	-
<i>Fertility levels (kg/ha)</i>		
N ₀ P ₀	1448	6.22
N ₂₀ P ₄₀	1788	7.10
CD (P=0.05)	171	-

Table 13. Effect of weed management practices on the yield and water use efficiency of rice

Treatment	Grain yield (t/ha)		Water use efficiency (kg/ha-mm)	
	2003	2004	2003	2004
Weedy check	4.02	4.18	2.25	2.3
Hand weeding (20 & 40 DAT)	5.39	5.62	3.02	3.1
Oxadiargyl (0.75 kg/ha)	4.84	5.31	2.72	2.8
Cinmethylin75g/ha	4.47	4.66	2.53	2.62
Oxadiargyl(75g/ha)+HW (40DAT)	5.61	5.83	3.14	3.20
Cinmethylin75g/ha+HW (40DAT)	5.21	5.42	2.19	3.02
CD P=0.05)	0.27	0.27	0.07	0.09

Table 14. Effect of mulching on seed yield and water use efficiency in chickpea

Treatment	Seed yield (kg/ha)	WUE (kg/ha-mm)
No mulch	1465	5.78
Weed straw mulch	1632	6.78
Polyethylene mulch	1757	7.40
CD (P=0.05)	152	-

plant vigourness, growth, yield and enables the plant to sustain efficiently under adverse condition. A study carried out by Khan and Singh [28] revealed that the application of

recommended dose of fertilizers significantly increased seed yield and WUE in chickpea grown in *Khadin* (Table 12). However, Dass *et al.* [12,18] reported that use of integrated nutrient management involving, chemical fertilizers, FYM/vermin- compost/*Gliricidia* green leaf manure, bio-fertilizers and 50% NPK dose led to higher productivity of finger millet in rainfed uplands of Eastern Ghats of Odisha. Singh Raj (2008) found significant increase in the seed yield of mothbean due to integration of FYM, chemical fertilizer and biofertilizer under arid regions of Rajasthan.

4.4 Weed Management

Weed is considered the major obstacle to successful crop production in rainfed agriculture. Rainfed agriculture is considered very weak for resources; further, the weed-generated competition with crop plants for resources makes it very difficult. Weed problems in the rainfed regions is more complex compared to irrigated conditions owing to several factors such as edaphic, climatic, social (small farm holdings, illiteracy and limited resources) and technological. A number of factors like climatic, geographical, cropping pattern, crop diversification and management practices determine the composition of weed species [56]. Weeds affect plant growth by competing for growth factors such as moisture, nutrients, light, and space, resulting in severe yield loss. Weeds interfere with agricultural operations, increase cost of cultivation and are potentially responsible for about 34% yield loss worldwide (Oerke, 2006). There are many weed species that have a higher water requirement than crop plants and reduce the crop yield. Hence, effective weed management is pre-requisite to reduce the yield loss occur due to severe crop-weed competition. An experiment conducted by Subramanyam *et al.* [61] at Tirupati to evaluate the efficiency of low dose herbicides under rainfed eco-systems. Among the weed management practices, oxadiargyl 75 g/ha + hand weeding at 40 DAT recorded the highest yield with lesser weed density over weedy check. The highest water use efficiency was also recorded in the same treatment (Table 13).

4.5 Mulching

Conservation of soil moisture is the most effective approach to obtain higher WUE and crop production in rainfed agriculture. A major

part (about 70%) of the conserved moisture is lost through evaporation and because of continuous loss of moisture crop suffers severely by moisture stress under rainfed condition. Mulching is one of the effective techniques to retain soil moisture in the soil by preventing moisture loss due to evaporation. It conserves the soil moisture and prevents soil loss by intercepting runoff and acting as insulation barrier for evaporation. Besides, mulching improves the soil fertility, soil structure, minimize the weed infestation, moderate the soil temperature and thereby increase the crop yield (Choudhary *et al.*, 2003; [12,17]. Many materials like straw, grasses, leaf, polyethylene, gunny bags, soils, etc. can be used for mulch purpose. Khan and Singh [28] found that polyethylene mulch was most effective for increasing maximum seed yield and water use efficiency in chickpea grown under conserved moisture condition (Table 14).

4.6 Alternate Land Use System

Alternative land use systems are a way of maximizing crop production and income per unit area and also to compensate weather complications under rainy conditions. Integration of many land use systems like Agri-horticulture, Agri-pasture, Agri-silviculture, Agro-forestry, and silvi-pasture in appropriate proportion can be advocated at the farm to realize yield and income in a sustainable manner. In addition to the upgrading and conservation of natural resources such as land, water and biodiversity, alternative land use systems ensure agricultural production and monetary return in the event of crop failure. Thus alternate land use systems assumes a greater importance for reducing the risk of vagaries of weather, improving environmental and land degradation, assuring production and income, and improving the livelihood of the resource poor farmers and sustainability in rainfed regions.

4.7 Agro-horticulture System

Growing of annual crops in between two rows of fruit crops is called agri-horticulture systems. This system is considered as an effective strategy for realizing sustainable crop production as it provides employment and monetary returns, protects the environment and land degradation, reduces the risk of weather uncertainty, and maintains the livelihood of the inhabitants of the rainfed areas even during drought years. In a

study, Yadav *et al.* [70] found that bael + clusterbean is a most suitable combination for obtaining highest B:C ratio, but the highest net return was realized with bael + groundnut under arid conditions (Table 15).

4.8 Agri-silviculture System

Agri-silviculture system is known to grow trees and field crops together in the same land at the same time. It is a very promising to improve soil fertility, micro-climate and moisture availability besides providing food, fodder, and fuel. Many studies showed that a tree density of 100–200/ha was found to be optimum for realizing higher yield and minimum interference on intercrops like cluster bean, moth bean and mungbean under canopy of tree species viz. *Prosopis cineraria* [4].

4.9 Agri-pasture Systems

Growing of crops along with grasses called Agri-pasture systems. In addition to stability in crop production, the removal of grass components acts as a barrier to prevent soil from wind and water erosion. Studies on intercropping of

grasses and legumes revealed that moth bean and mungbean in the ratio of 2:1 with grasses viz. *Lasiurus indicus*, *Cenchrus ciliaris* and *C. setigerus* found better than sole arable or grasses under arid condition. A study carried out by Singh and Gupta [50] revealed that strip cropping of legumes and grasses holds promise, increasing grain yields significantly over the control.

4.10 Cropping Systems

Efficient cropping system can contribute to a great extent for enhancing crop productivity and conserving natural resources. An effective cropping system improves soil physico-chemical properties and WUE, besides increasing crop productivity. In a study Nanwal *et al.* [36] observed that priority to the cropping systems should be given considering the moisture availability and growing period (Table 16). A study was carried out at IARI, New Delhi by Singh *et al.* [54] indicated that use of diversified cropping systems (Babycorn –mustard) not only increased the system productivity and net profit but also resulted in higher income per day (Table 17).

Table 15. Economics of different agri-horti system at Bikaner

Agri-horti system	† profit (Rs/ha)	C ratio
Ber+mothbean	10854	2.06
Ber+clusterbean	12970	2.33
Ber+groundnut	20379	2.45
Bael+mothbean	14310	2.86
Bael+clusterbean	16054	3.02
Bael+groundnut	21799	2.75
Kinnow+mothbean	11015	2.20
Kinnow+mothbean	11122	2.10
Kinnow+mothbean	19830	2.50

Table 16. Potential cropping systems in relation to rainfall and soil type

Rainfall (cm.)	Soil Type	Effective growing season (weeks)	Cropping system
320-600	Red & shallow black soils	20	Single <i>kharif</i> cropping
350-600	Deep Sierozems and alluviums	20	Single cropping in either <i>kharif</i> or <i>rabi</i>
350-600	Deep black soils	20	Single <i>rabi</i> cropping
600-750	Red, black and alluvial soil	20-30	Inter cropping
750-900	Alluviums, deep black, deep red and sub- mountainous soils	>30	Double cropping with monitoring
>900	Alluviums, deep black, deep red and sub monotonous soils	<30	Double cropping

Table17. Effect of different cropping systems on the system productivity and economics in rainfed condition

Cropping system	System productivity in terms of pearlmillet yield (t/ha)	Net eq.returns (Rs/ha)	B:C ratio	Income (Rs/ha/day)
Babycorn-mustard	15.61	122629	1.42	573.0
Cowpea (veg)-barley	9.03	52305	0.72	251.47
Greengram-chickpea	8.94	48118	0.66	227.31
Pearlmillet-lentil	5.50	17271	0.31	82.64

Table 18. Crop productivity and economics as influenced by crop diversification in rainfed condition

Cropping systems	Pearlmillet equivalent yield (ton/ha)	Net seedreturn (Rs/ha)	B:C ratio	Increase in net returns over pearlmillet-lentil cropping systems (Rs)
Babycorn-mustard	15.61	122629	1.42	105358
Cowpea (veg.)-barley	9.03	52305	0.72	35034
Greengram-chickpea	8.94	48118	0.66	30847
Pearlmillet-lentil	5.50	17271	0.31	0

4.11 Integrated Farming System

In recent years continuous increase of the biotic pressure on the land and over-exploitation of natural resources (water, soil, and bio-diversity) is causing problems for sustainable agriculture. Many problems like declining groundwater table, degradation of soil fertility, land, and natural resources are arising, resulting in low and unstable yield. Under such a situation, it is imperative to develop efficient technologies that are capable of avoiding degradation of natural resources, increasing sustainability in agricultural production, helping employment and income, and maintaining ecological and environmental balance. Integrated farming system (IFS) is one of the possible approaches that prevent environmental degradation, stabilize crop production, increase income through employment generation and improve environmental quality through balanced use of resources.

Many IFS models have been developed across the country considering the climatic conditions, cropping pattern, demand of commodities, rainfall, and soil and. Further, selection of appropriate enterprises for the IFS is of vital importance. Enterprises should be selected based on the principle of minimum competition and maximum complementary effect on each other. Studies carried out in different parts of the country indicated that recycling of crop residues and animal manure could supply 26.0, 22.3 and

26.0 kg NPK to field and fodder crops through bio-compost and 39.4, 10.5 and 18.0 kg NPK to vegetable crops as vermi-compost in one acre area in rainfed condition of TamilNadu [26]. The IFS with 2 bullocks + 1 cow + 1 buffalo + 10 goats along with poultry and duckery was the most beneficial system for the marginal farmers in rainfed regions of Chhattisgarh in Central India [42]. IFS approach with the combination of crops (rice, off-season tomato, cauliflower) and non-crop enterprises like poultry + paddy straw mushroom production + vermi-composting was sustainable system giving a maximum net return and additional employment under rainfed risk-prone situations in Deogarh district of Orissa [6]. In a study, Singh *et al.* [57] found that farmers can earn 82.5% more profits (Rs.135.82 thousand/ha/year) than crops alone (Rs.74, 435/ha/year).

4.12 Crop Diversification

Crop diversification is intended to give a wider choice in the production of a variety of crops in a given area so as to expand production related activities on various crops and also to lessen risk. It is based on the cultivation of more than one type of crops belonging to the same or different species in a given area for the purpose of increasing production and income per unit area and conserving resources. Crop diversification is one way of developing a flexible farming system, especially where communities depend largely on agricultural products (food and

fodder) for their livelihoods [35]. Diversified farming reduces risks associated with yield, market, and prices, arrest the degradation of natural resources and environment, attain national goals like self-reliance in critical crop products, earning foreign exchange and employment generation. It also helps to raise farm income, provide sustainable production, and achieve food and nutritional security and also to reduce environmental pollution and to conserve biodiversity. A study carried out at IARI, New Delhi by Singh *et al.*, (2019) revealed that the introduction of babycorn-mustard cropping systems in rainfed condition fetched Rs. 122629/ha as net returns compared to Rs.17271/ha with pearl millet-lentil cropping systems (Table 18).

4.13 Watershed Management

A watershed is a geo-hydrological unit of a topographical area that drains the water by a single outlet point or through common drainage. Watershed is also known as a catchment area of the draining outlet that can convert into a larger stream and join a river. Uncontrolled flow water promotes soil erosion, loss of soil fertility and biodiversity, resulting in degradation of natural resources. The watershed development is an effective approach to rehabilitate degraded natural resources and also to check the soil erosion through judicious use of all available low-cost technologies. Soil fertility and crop productivity can be improved through the conservation of flow water and the adverse effect of drought can be mitigated under rainfed condition. Furthermore, due to conservation of biodiversity, grasses and afforestation, it

increases the availability of fodder and fuel and also reduces the ill effects of climate change. Due to afforestation and biodiversity conservation, it tackles the problem of desertification and restores ecological balance. It also improves the socio-economic status of farmers by increasing crop and livestock production. Further, groundwater recharge and occurrence of the flood can be controlled through watershed management. Overall watershed management approach should be promoted for the sustainable development of the watershed area under rainfed condition. Many technologies like agronomical (strip cropping, plantation of grasses and forestry plants) and engineering measures (contour bunding, contour trenching, terracing, construction of earthen embankment, check dams, *anicuts*, farm ponds, diversion, structure, *Khadins*, rock dam and providing vegetative and stone barriers and vegetation cover) can be used to manage the watershed area. Patnaik *et al.*, [40] reported that holistic development of watershed doubled the tribal farmers' income and later, Dass *et al.*, [20] reported that collective effect of various agronomical management practices resulted in overall 33% increase in cropping intensity and 33 to 112% increase in crop yields in Kokriguda watershed in Koraput District of Odisha. Khan *et al.* [27] reported that average yield of pearl millet, mungbean, mothbean and clusterbean was increased by The grain yield of pearl millet, mungbean, mothbean and clusterbean was increased by 59.3, 58.3, 57.9 and 41.9%, respectively after commencement of watershed management activities compared to before commencement of the activities under rainfed condition of arid zone.

Table 19. Effect of conservation agriculture on the yield, economics and water use efficiency of different *rabi* crops in rainfed condition

Treatment	Chickpea grain eq. yield (kg/ha)	Net return (Rs./ha)	Water use efficiency (CEY kg/ha-mm)
<u>Crops</u>			
Pearlmillet-chickpea	2260	56537	3.69
Pearlmillet-lentil	1616	29526	2.64
Pearlmillet-barley.	1883	42423	3.07
<u>Conservation agriculture</u>			
Conventional tillage	1777	30465	2.90
Residue as standing retention in zero tillage	1907	45357	3.11
Residue as mulch in zero tillage	2078	51917	3.40

4.14 Conservation Agriculture

Traditional agriculture in rainfed conditions has been experiencing low agricultural productivity as the lands suffer from low soil moisture, poor soil fertility, susceptibility to water erosion and other external pressures of development and climate change. A shift towards more sustainable crop production approach such as conservation agriculture (CA) production systems may help in maintaining soil moisture status, soil fertility and quality as well as improving crop production and farmer's net economic benefit. Three principles of CA like minimal or no soil disturbance, permanent soil cover (mulch) and crop rotations are helpful to reduce ill effects of tillage, reduce soil compaction and soil biota loss, increase water infiltration, reduce evaporation, moderate soil temperature, reduce weed infestation, improve soil fertility, increase microbial diversity, reduce the risk of pests and disease outbreaks from pathogenic organisms. Results from a study shown in Table 19 indicated 14.48, 0.41 and 14.7% increase in the yield, net returns and water use efficiency, respectively from the crops grown during winter season crops with the use of residue mulch in zero tillage compared to conventional tillage under rainfed condition [54].

5. CONCLUSION AND FUTURE STRATEGIES

The food grain demand of the country is increasing by leaps and bounds owing to the continuous increase of country's population. As per projection made Indian Agricultural Research Council, New Delhi in vision 2050 that country's population will be 1650 million by the end of 2050 and country would require 400-million-ton food grain to feed increased population. Thus providing sufficient food grains will be one of the great challenges before the administrators, policy makers, scientists, and farmers. About 60% of the total net irrigated area is dependent on groundwater based irrigation sources like wells, tube wells, tanks, etc. Due to over- exploitation and limited recharging, groundwater availability is affecting drastically resulting in continuous decrease in the groundwater table. Moreover, the productivity of the irrigated area is also not much improving because of indiscriminate use of industrial inputs, decrease in soil fertility and quality, reduction of total factor productivity and non-adoption of suitable farming practices. Further, there is a little possibility to bring more

area under irrigation as water demand is rapidly increasing for non-agriculture activities like industry, energy, developmental activities, and domestic consumption. Further, the small and marginal production system is pre-dominating in the country. According to the 2015-16 Agricultural Census [3], the total number of operational holdings was 145.73 million with an average size of 1.08 ha. Of the total holdings, 86.08% are in marginal and small farm categories holding > 2 ha land. Therefore, priority should be given to increase the productivity per unit area of rainfed agriculture, which is about half of irrigated agriculture. There is a need for a paradigm shift in emphasis towards improving agriculture management practices. About 72 m ha of the net sown area (52%) is still completely dependent on rainfall that cannot be productive unless it is covered with improved production technologies. Rainfed areas constitute about three-fourth of land mass under arid, semi-arid, and dry humid situations, and are, therefore, more vulnerable to weather aberrations. This area is characterized by low levels of productivity and low input usage and are highly prone to the ill-effects of agro-climatic, edaphic and socio-economic factors. As a result, experience frequent hardships like drought coupled with partially or completely crop failures. But rainfed areas, if managed properly with the adoption of improved production technologies, holds tremendous potential to contribute a larger share to food grain production of the country and faster agricultural growth compared to the traditional rainfed agriculture. The essential pre-requisite is crop alignment with agro-climatic status. Further, the Indian climate, which is predominantly tropical and subtropical, receives most of its rainfall from the south-west monsoons with high intensity resulting in high runoff and degradation of the land mass. In rainfed regions, due to the temporal and spatial variability, and due to the skewed distribution of rainfall, crops invariably suffer from moisture stress at one or the other stage of crop growth. Thus, rainfed agriculture needs immediate attention for devising appropriate, sustainable and implementable technologies to improve productivity. In addition, more attention needs to be paid on appropriate measures to overcome the climatic, edaphic, technological and socio- economic constraints. More efforts need to improve the productivity of rainfed agriculture through the adoption of sustainable technologies. Following are some of the suggestive measures for improving rainfed agriculture:

- Characterization of bio-physical and socio-economical resources to maximize the usefulness of available resources by imposing improved technologies.
- More emphasis is required to develop and adopt drought-resistant varieties, resource conserving production system and technologies.
- Enhancement of rainwater use efficiency through storage, budgeting, and application of rain water by efficient irrigation methods.
- Crop diversification, intensification and post-harvest technologies need to be popularized at the on-farm condition.
- Priority should be given to alternate land use system, integrated farming systems, conservation agriculture and watershed development for sustainable agricultural production.
- A special programme like evergreen revolution programme for rainfed agriculture needs to be launched across the country to sustain the agricultural productivity of these areas.
- Holistic solutions are needed through convergence, cooperation and collective action at the grass root level.
- Capacity building, innovations, enabling policies, funding support, and adaptations strategies can play a vital role to sustain the rainfed agriculture.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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